Tillage systems for soil and water conservation

FAO
SOILS
BULLETIN
54

FOOD
AND
AGRICULTURE
ORGANIZATION
OF THE
UNITED NATIONS

FOREWORD

The Food and Agriculture Organiaation of the United Nations (FAO) has been concerned with the need for soil and water conservation since its establishment in 1945. Since that time, FAO has supported numerous projects, sponsored or participated in various conferences and seminars, and published various bulletins, reports, proceedings, etc. to focus attention on the nature of this worldwide problem and to provide information regarding remedial action to be taken to alleviate the problem. However, the problem remains, and the increasing world population is resulting in intensified cropping of the limited areas of arable land to provide the necessary food in some countries. Unless effective conservation practices are used, such intensive cropping tends to increase the loss of soil and water resources. This trend must be reversed.

The objectives of this Soils Bulletin are to present the principles and practices of tillage systems for sustained food production and to create an awareness of the need to conserve the world's soil water and energy resources for future generations. Although energy is an integral part of tillage systems, the emphasis is on soil and water conservation. However, effects of the systems on energy are discussed where appropriate.

This Bulletin emphasizes tillage systems for developing countries, but relies heavily on principles that have been developed throughout the world. It is intended mainly for the training of and use by extension workers for improving crop production through use of improved tillage systems for conserving the soil and water resources in developing countries.

Since not all the solutions to particular soil conditions are yet known, the need for more research on conservation tillage in developing countries is stressed.

ACKNOWLEDGEMENTS

The Food and Agriculture Organization of the United Nations is greatly indebted to the Agricultural Research Service of the US Department of Agriculture and in particular to its Conservation and Production Research Laboratory at Bushland for permitting Dr. Paul W. Unger to research and write this bulletin over a period of time. FAO is most grateful for his assistance.

The author is a noted Soil Scientist with years of experience in conservation tillage research under a range of conditions. He has published about a hundred papers, many dealing with conservation tillage, and is one of the most renowned experts in this field.

Though material for this publication has been drawn in large part from the USA where most of the experience on conservation tillage exists, results from developing countries have been taken into due consideration and cited.

The author has used illustrations from many sources and acknowledges with thanks permission to use copyright material. In all cases credits are given under the appropriate illustration or with the table.

The author wishes to express his sincere gratitude to FAO for the invitation to prepare this bulletin, to the USDA Agricultural Research Station for permitting him to accept the invitation, and to the many people who helped in numerous ways to make this bulletin possible. Special thanks go to Drs. M.D. HIeilman and B.A. Stewart of the USDA Agricultural Research Service and to Dr. D.M. Van Doren Jr., of the Ohio Research and Development Center for reviewing and offering suggestions for improvement, and to Mrs. Lynette Lott for typing the original and several Revised versions of the manuscript for the bulletin.

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1. INTRODUCTION

1.1 OPENING STATEMENTS

Early man, living as a nomad, obtained his food and made his clothing from naturally occurring plants and animals. Such nomadic existence was satisfactory when natural resources* were abundant and populations were low. Even today, people use a nomadic way of life in some parts of the world.

As populations increased, the natural supply of plants and animals became inadequate to supply man’s needs. It then became necessary for him to relinquish the nomadic existence and to practice crop and animal production on limited areas. Crop culture was usually confined to a rather small area. Animals, after domestication, were an integral part of the settler’s enterprise and foraged not only on surrounding areas, but also on areas used for crop culture where they were watched attentively. A close association between crop and animal production is still common in most countries.

In the early stages of the development of crop culture, vegetation that surrounded and competed with plants that provided food was flattened or removed by hand. Food production was generally limited under these conditions. As man learned to grow certain food plants in the more desirable locations, it became necessary to remove existing vegetation, which heralded the beginning of soil tillage* (Shear in press).

Early crop producers used crude implements of wood or stone to till their soil, and wooden implements are still used in some parts of the world. With these implements, they loosened the soil without burying deeply the organic materials on the surface (Duley and Mathews 1947), and crop production was generally in equilibrium with prevailing conditions. Gradually, producers realized that competition by weeds was primarily responsible for restricted growth of food plants (Shear in press), and improved implements and techniques for controlling weeds have been sought ever since. Weed control is one of the basic reasons usually given for tilling a soil.

Although soils are tilled to control weeds and for other reasons (see later section), the underlying goal of soil-manipulating activities, including tillage, is to stabilize and increase crop production. The subsistence farmer in a developing country is interested primarily in a stable supply of food for himself and his family, and of feed for his livestock. Production above this basic level is often of little importance because the excess products can seldom be preserved or stored, there is little or no transportation for hauling the products to market, or there may be no market for the product. Increased crop production is an important goal for farmers where transportation is adequate and where suitable markets are available.

The quest for stabilized and increased crop production has been accompanied by a quest for improved implements for soil tillage. Although pointed sticks, hoes, forks, and spades are still the basic implements of many of the world’s farmers (Figs. l, 2, 3), a vast array of implements has been developed for soil tillage. These include ploughs, disks, harrows, chisels, and other soil disturbing implements that are operated either individually or in various combinations (Figs. 4, 5, 6, 7, 8).

* See Appendix 1 - Glossary. Throughout the text, the asterisk beside a word indicates that it is given in the Glossary.

Fig. 1

A farmer in Ethiopia digging potatoes with a primitive tool (FAO photo)

Fig. 2 "Ploughing" by hand in Upper Volta (WFP photo, issued by FAO)

Fig. 3 Workers preparing land for planting in Jordan (FAO photo)

Fig. 4

Hand tillage equipment in Bangladesh (FAO photo)

Fig. 5 Primitive plough (goose-foot cultivator) in Chile (FAO photo)

Fig. 6 Preparing a seedbed for millet in Niger (FAO photo)

Fig. 7 Disk plough in Libya (FAO photo)

Fig. 8 Chisel plough (photo provided by C.R. Fenster, University of Nebraska)

For centuries, the plough has been the basic implement and symbol of farming. Development and use of the plough, from its humble beginning as a crooked stick to the modern steel mouldboard plough, required the efforts of man in all ages. Use of the plough aided weed control and prepared the soil for planting. However, it has long been recognized that the resultant clean-tilled land loses more soil by erosion than land that has crop residues on the surface or is covered by growing vegetation (Duley and Mathews 1947).

Although clean tillage* per se, when improperly used, is a major contributor to erosion, other major contributors include forest clearing, overgrazing, poor land management, excessive removal of crop residues, and improper use of farming practices (Figs. 9, 10, 11, 12, 13). Unfortunately, much of the world's arable land* has been or is being damaged by erosion, some of it so severely that it is no longer suitable for agriculture. Other arable lands in some countries are being usurped at alarming rates for non-agricultural purposes, such as for residential and business areas, industrial sites, airports, roads and highways, and recreational areas (IUCN 1980).

The world's area of potential arable land is finite, but the world's population continues to increase. In some countries, arable land is plentiful, in others it is extremely limited. On a worldwide basis, there is an urgent need to conserve and use wisely our remaining land resources for sustained aqricultural production.

Water not only provides direct sustenance to plants, but is also a factor in soil erosion through its effect on detachment and transport of soil particles and the production of plant materials that can be managed for erosion control. Development and adaptation of fuel energy based crop production systems would alleviate the drudgery of manual labour where it is used. It would also permit food production for humans on land that is currently used for feed production for draught animals. However, there would be increased demand for petroleum-based fuels that are highly important for mechanized agriculture, but are also in short supply, being depleted, and are expensive.

Fig. 9 Shifting cultivation in Indonesia. Bare soil resulting from forest clearing on sloping land provides little protection against erosion (FAO photo)

One method of achieving soil, water and energy conservation is to develop and adapt tillage systems that are most suitable for the prevailing soil, crop and climatic conditions. Under some conditions, a simple change in tillage method may be adequate; in others, major changes along with the use of one or more supporting practices, such as contouring, terracing, strip cropping, residue management*, etc., may be required. If the concern for soil and water conservation* were universal, suitable tillage systems and supporting practices could be

Fig. 10 Intensive grazing by sheep contributes to soil erosion (FAO photo)

Fig. 11 Women of Togo carrying crop products from fields. Removal of all crop residues for fuel increases the potential for erosion (FAO photo)

Fig. 12 Soil erosion and silt deposition in clean-tilled maize field with rows up and down the slope in Illinois (USDA-Soil Conservation Service photo, issued by FAO)

Fig. 13 Slope steepness and length affect soil erosion. Proper land use and conservation practices are necessary to control erosion on land such as this (Iowa State University photo, issued by FAO)

implemented to virtually eliminate soil erosion and greatly improve water conservation. However, this concern is limited and often government policies, commodity prices, production goals, producer preferences and education, social customs, religious beliefs, land ownership, and short-term goals receive greater emphasis than the adoption of sound conservation measures.

Although the farmer is the ultimate user of conservation practices, society as a whole benefits through conservation of natural resources and a sustained food production capability. Consequently, the farmer should benefit from his conservation efforts. Benefits may be in the form of direct subsidies or support for research for the development of improved conservation practices that are as manageable and reliable as presently used crop production practices. If such practices were readily available, farmers would accept them on economic grounds and erosion would be controlled without further inputs from society.

1.2 OBJECTIVE

The objective of this report is to make a “state of the art” presentation of the principles and practices of tillage systems for conserving soil, water and energy resources for sustained food production to meet the needs of an ever-increasing world population. Using energy is an integral part of tillage systems, but the emphasis will be on soil and water conservation. However, when appropriate, effects of the systems on energy will be mentioned or discussed.

In this report, specific examples, along with background information, will be provided mainly for rainfed agriculture on different soils or groups of soils and for different crops in semi-arid, subhumid and humid climatic regions for which numerous reports are available. Examples and information for irrigated systems will be given where appropriate, mainly for systems in semi-arid regions. Information from systems in semi-arid regions will be extrapolated for use in arid regions, thus exploring the potential for improved crop production in fringe areas of the arid regions.

1.3 INTENDED AUDIENCE

The principles of the various tillage systems discussed in this report are applicable whenever crops are grown. The actual practices employed, however, will vary depending on the state of development of agriculture in a particular country or region. Although practices from developed countries will be mentioned, the emphasis will be on practices for use in developing countries.

In particular, this report is intended for the training of and use by extension workers for improving crop production through the use of improved tillage systems for conserving the soil and water resources in developing countries.

1.4 SUMMARY AND CONCLUSIONS

The following summary and conclusions are placed early in this Bulletin for the reader who desires only to obtain an overview of the ideas presented. For a more detailed discussion of the different tillage systems with respect to soil and water conservation, the interested reader is encouraged to read the entire bulletin.

1. Uneven distributions of arable land and human populations are common in the world. Increasing populations and limited arable land are

placing severe pressures on land resources, especially in some developing countries.

2. Intensive cropping due to increasing populations is resulting in serious land degradation in countries where effective soil and water conservation practices are not used.

3. Land degradation diminishes the crop production potential of agricultural lands. Numerous factors cause land degradation, but that caused by erosion, sedimentation, salts, alkali, organic wastes and infectious organisms (weeds, insects, diseases) is considered of greatest importance and requires immediate action to prevent a state of emergency from being reached.

4. Most agricultural lands are subject to erosion, mainly by water and wind. Associated with these is sedimentation and, in some cases, salinization and alkalization. Infectious organisms, unless controlled, limit production of most crops.

5. The ultimate solution to the land degradation problem is to use each tract of land according to its capabilities. This is practical where land resources are abundant, but is usually not practised where population pressures are high, arable land is limited, or the need for conservation practices is not fully recognized by all concerned. Successful implementation of effective conservation practices requires the cooperation and support of all entities involved (governmental, regional, commodity, local, farmer, etc.).

6. The goal of tillage is to provide a favourable environment for crop growth and production, but still conserve soil and water resources. Where resources cannot be effectively conserved by tillage alone, then supporting practices such as contouring, strip cropping, terracing, etc. may be required.

7. Some form of cultivation system is involved in the production of all crops. Types discussed in this report are shifting, labour intensive continuous, animal draught and small tractor, and modern high technology. Each is appropriate for crop production in some situation based on such factors as land resources, climate, crops grown, soils, markets, economic level of producers, producer preferences, etc.

8. Shifting cultivation leads to serious land degradation when the fallow period is too short and where poor land management is used. Shifting cultivation has provided for sustained crop production for many years where good management practices were used.

9. Labour intensive continuous cultivation replaces shifting cultivation where land resources are limited. It has the latent possibility for land degradation where improperly used, but also the potential for soil and water conservation, sustained crop production, and high yields with good management.

10. Animal draught and small tractor cultivation reduce the labour requirement for crop production, but may not be practical because of limited capital, small or fragmented land areas, and unavailability of suitable markets and infrastructure.

11. Modern high technology cultivation depends on fuel energy and other chemicals to replace labour for crop production. The system is widely used in developed countries, but is also applicable to

developing countries when land, capital, equipment and other resources are available, and where labour is limited or relatively expensive.

12. Clean tillage is adaptable for most crops and minimizes crop production problems, but can lead to greater soil and water losses than other tillage methods on some land.

13. Conservation tillage usually relies on management of surface residues to minimize soil and water losses. Types include stubble mulch tillage, minimum or reduced tillage, and no-tillage. Suitable types of conservation tillage have been developed for many crops, but some types (especially no-tillage) are relatively new and some problems remain to be solved. The major problems are concerned with equipment, weed control, herbicide availability and cost, crop yields (some soils), and farmers' managerial ability.

14. The minimum, reduced and no-tillage systems reduce energy, labour and equipment requirements for crop production. Therefore, if crop yields are increased, equal to, or decreased only slightly, then crop production is more economical than with other systems. No-tillage is generally not adapted to poorly drained soils and to some soils in cool regions.

15. A dust or soil mulch may conserve water already in soil (stored during the rainy season), but is seldom effective for storing water during a fallow period because the mulch must be re-established after each rainstorm, and the mulch is highly susceptible to wind and water erosion.

16. Continuous cropping usually results in greatest yields of the most desirable crop, but may lead to greater weed, insect and disease problems. It may also lead to increased soil and water losses, especially for crops that produce inadequate amounts of crop residues for management in conservation tillage systems.

17. Crop rotations enhance soil and water conservation if one or more of the crops produce relatively large amounts of residue. Use of rotations may also improve crop production efficiency by improving the utilization of soil, water, nutrient, equipment and labour resources.

18. Multiple cropping enhances the potential for greater overall crop production by growing two or more crops on the same land by sequential or intercropping as compared with one crop during the same period by monocropping. Multiple cropping requires that water, climate and other resources are favourable for such intensified .crop production. By providing for plant cover on the land for a greater portion of the time, multiple cropping enhances soil and water conservation as compared with monocropping.

19. On other than Class I land, conservation practices other than tillage per se are usually needed to conserve soil and water resources effectively. However, no-tillage with adequate surface residues can conserve soil and water resources on Class II and III lands. Where such tillage is not used, surface manipulation practices are usually required. On relatively gentle slopes, only minor soil surface manipulation (for example, smoothing, contouring, strip cropping, basin listing, etc.) may be satisfactory. On more sloping soils, terracing, bench levelling, waterway construction, gully control, etc. may be required to protect the soil adequately and to conserve water for sustained crop production. By proper planning, construction and maintenance of bench terraces, crop production has been

maintained on some steeply sloping lands for many years without land degradation.

20. Many types of equipment are available for use in all cultivation systems. The types range from hand implements for shifting and labour intensive continuous cultivation systems to mainly animal or tractor powered equipment for the animal-drawn, small tractor and modern high technology cultivation systems. Regardless of cultivation system used, the equipment can be employed to achieve soil and water conservation. However, the producer must be apprised of the need for conserving resources and must achieve an economic benefit from applying conservation measures. Society as a whole (for a given country, region, or the entire world) benefits from resource conservation; therefore, society as a whole should be concerned with and help bear the expenses of resource conservation. This can be accomplished by paying fair prices for crops produced, by providing monetary or other incentives for applying conservation measures, and by education, extension activities, etc., to apprise the producer of the long-term benefits of conserving the resources. Only when all segments of society realize the need for and participate in the conservation of resources will true conservation be achieved for sustained crop production for an ever-increasing world population.

2. LAND DEGRADATION

2.1 TYPES

Agricultural lands diminish in crop production potential or suitability for crop production through various types of land degradation*. All types are not equally important based on areal coverage, intensity or rate of degradation, and impact on soil productivity. Recognizing the relative importance of the various types of land degradation, Rauschkolb (1971) proposed three categories as a guide for use of resources to solve the problems. Included in Category I are erosion and sedimentation, salts and alkali, organic wastes, and infectious organisms (weeds, diseases and insects). Rauschkolb (1971) considered these types of greatest importance and indicated that immediate action is required to apply available technology or develop new technology to prevent land degradation from these causes from reaching a state of emergency.

Category II included industrial inorganic wastes, pesticides, radioactive substances and heavy metals. These causes were considered of lesser importance than those in Category I because of their lesser extent, intensity, or rate of increase. Fertilizers and detergents were included in Category III, which was considered to be of lowest priority for remedial action because they constituted no widespread hazard to soils and occurred only in isolated areas.

Although not included in the above categories, Rauschkolb (1971) discussed land subsidence caused by extraction of water, oil, or gas, and by mining activities as a form of land degradation. Another form, at least from an agricultural viewpoint, is the conversion of agricultural lands into urban areas, industrial sites, roads and highways, airports and recreational areas. While these may be “signs of progress”, wise long-range planning could minimize the adverse effects of these activities on present and future production.

All types of land degradation in Categories I, II and III are affected by tillage systems and related practices. In this report, however, the emphasis will be on those in Category I, and most explicitly on erosion (including sedimentation, desertification and dune creep) and on salinization and alkalization. Management of organic wastes, especially crop residues, and infectious organisms are integral parts of tillage systems, and will, therefore, be discussed as appropriate.

2.1.1 Erosion

i. Types

Soil erosion and concomitant sedimentation in ages past and at present are responsible for some of the major agricultural areas of the world. Paradoxically, past and present day erosion is also a major form of land degradation that has rendered or is rendering vast areas of land useless with respect to crop production (Rauschkolb 1971)

Plaisance and Cailleux (1981) listed classifications of erosion based on mode of action as chemical, running water, en masse movement, wind and biological. All these have been involved in geological erosion (as opposed to accelerated erosion caused by man), which has resulted in wearing down of mountains, cutting of canyons and wearing away of landscapes. Many and probably all of the world’s great agricultural areas have resulted from geological erosion.

Wind and water erosion are of major importance with respect to tillage systems, and the main emphasis in this report will be on these types. Tillage erosion (Papendick and Miller 1977; Wright 1977), a type of en masse movement, is of considerable importance under some conditions, and will be discussed to a limited extent. Chemical and biological erosion have little relevance with respect to tillage systems and, therefore, will not be further discussed.

Soil erosion by wind and water was the subject of two FAO Agricultural Development papers reprinted in 1978 (FAO 1978a, 1978b). Numerous other reports are contained in the literature. In this report, therefore, the basic principles of erosion processes and control will be discussed only briefly. Likewise, the magnitude and consequences of erosion will also be discussed only briefly.

a. Wind erosion

Soil erosion by wind is a potential problem wherever certain soil, vegetation and climatic conditions prevail. The conditions are (1) a dry, loose soil that is reasonably finely divided; (2) a smooth soil surface on which little or no vegetative cover is present; (3) a large enough field; and (4) wind that is strong enough to move soil (Skidmore and Siddoway 1978).

A generalized equation expressing the relative quantity of wind erosion from a field was first published by Chepil (1959). As new data have become available, the equation has been modified and is now generally given as

$$E = f(ICKLV) \qquad [1]$$

where E is the potential annual quantity of erosion per unit area and is a function, f, of I, soil erodibility; C, local wind erosion climatic factor; K, soil surface roughness; L, equivalent width of field (maximum unsheltered distance across the field along the prevailing wind erosion direction); and V, equivalent quantity of vegetative cover (Chepil and Woodruff 1963). The mathematical relationships among the components of the equation are complicated. The relationships, however, have been computed and developed into tables or plotted on graphs, and are useful for estimating annual soil losses by wind erosion and for determining alternate land treatments for wind erosion control. A guide containing this information for the Great Plains states (USA) is available (Craig and Turelle 1964). Tillage has a direct bearing on factors I, K and V through its effect on soil cloddiness, soil roughness and equivalent quantity of vegetative cover.

Sandy soils are extremely susceptible to erosion by wind because of little or no coherence between particles, small particle sizes and rapid drying (Figs. 14, 15). Severe erosion, however, may also occur on other soils when they are dry and loose, and when the particles have been finely divided by raindrop impact, freezing and thawing, or tillage. Particles greater than 0.84 mm in diameter are usually considered non-erodible by wind.

Provided other conditions are met, soils having smooth surfaces are highly susceptible to wind erosion. Smooth surfaces result from (1) tillage operations that break up surface clods and eliminate or incorporate surface residues (Fig. 16), (2) raindrop impact, (3) freezing and thawing, and (4) erosion itself. Tillage methods that provide a roughened soil surface by producing and maintaining clods and ridges on the surface and that retain adequate residues on the surface are desirable for controlling erosion by wind (Fig. 17).

Fig. 14 Sand dunes in Pakistan (FAO photo)

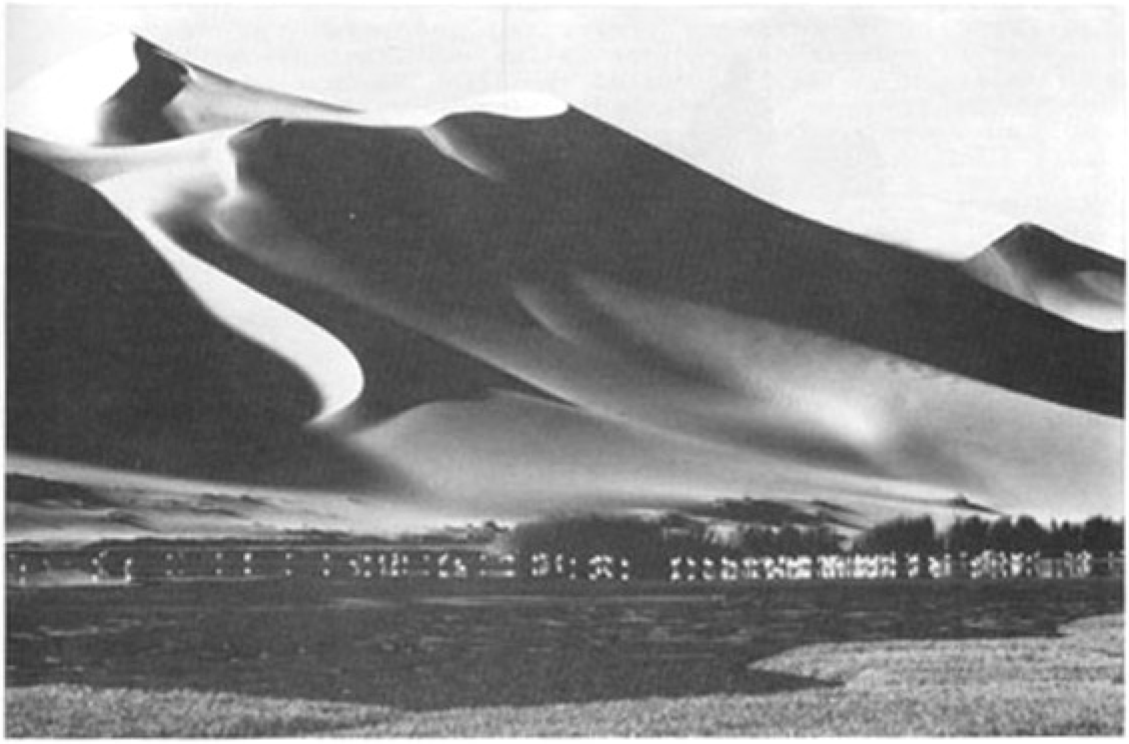


Fig. 15 Sand dunes of the Namib desert, Namibia (photo by James Brandenburg, copyrighted by National Geographic Society, June 1982)

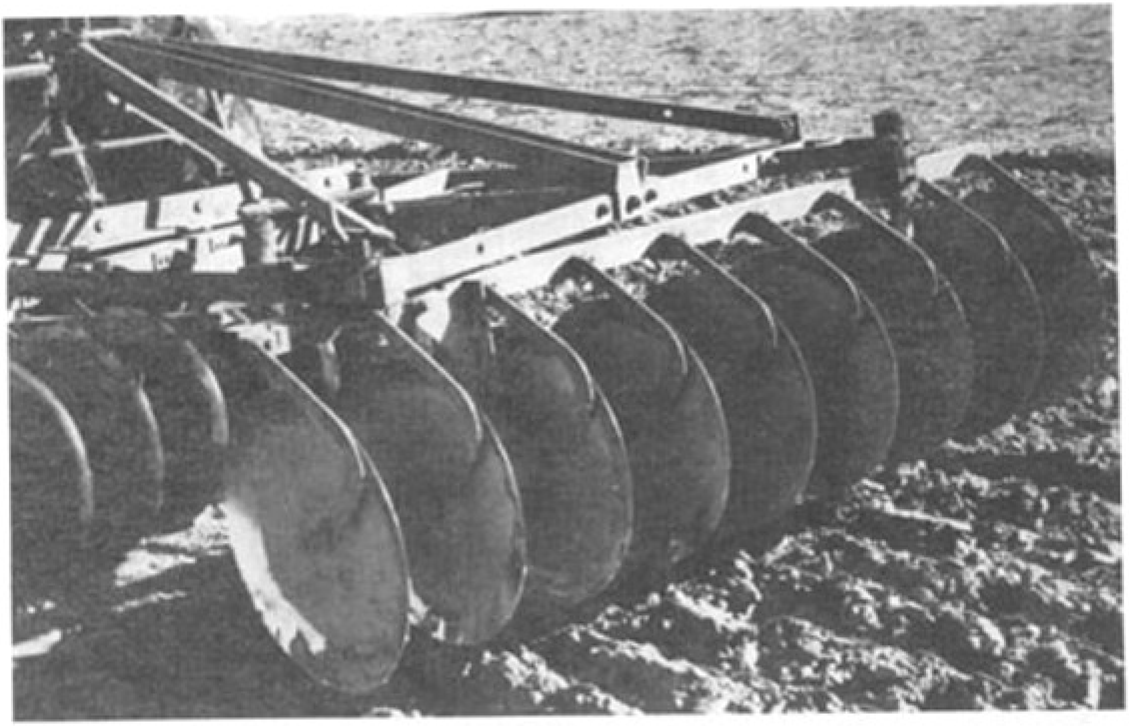


Fig. 16 Disk ploughs or harrows, which often result in a relatively smooth soil surface are usually less effective for soil and water conservation than some other implements (FAO photo)

Fig. 17 A heavy-duty cultivator leaves a residue-covered, cloddy surface which reduces soil and water losses (FAO photo)

Soil erodibility increases as distance between wind barriers which are perpendicular to the wind direction increases. Field width in the direction of prevailing winds should, therefore, be kept as narrow as practical. However, this may not prevent wind erosion because some fields that are only a few metres wide erode (Skidmore and Siddoway 1978). The effect of field width is minimized when the surface is sufficiently rough due to tillage or surface residues.

Soil movement begins at relatively low wind speeds and progressively increases as wind speed and turbulence increase (Chepil and Woodruff 1963; FAO l978a). To minimize erosion, therefore, wind speed at the soil-air interface must be reduced to the threshold value below which no significant wind erosion will occur (Skidmore and Siddoway 1978). The effect of wind on soil erosion is extremely complex and includes the processes of soil movement (saltation, surface creep and suspension), transport, sorting, abrasion, avalanching and deposition (Woodruff and Siddoway 1973).

b. Water erosion

Soil erosion by water may occur at any time on most soils when water flows across the surface, unless the surface is adequately protected by residues or other erosion-control practices. However, the potential is usually greatest while the surface is bare after ploughing, during seedbed preparation, and at seedling establishment. Surface residues and growing crops are especially effective for controlling erosion by water (Hayes and Kimberlin 1978; Wischmeier 1973).

Soil erosion by water involves particle detachment and transport, which require energy. Rainfall and flowing water (runoff) have potential for detaching particles, but transport is mainly by runoff; however, raindrop splash action also transports particles. The energy at upslope positions is supplied mainly by rainfall and slope gradient. On bare soil, the kinetic energy of raindrops is mainly dissipated at the surface where impacting drops may detach soil particles (Fig. 18). Splash action and shallow sheet flow of water then transport detached particles to runoff concentrations (Fig. 19). Raindrop impact may also disperse soil aggregates, reduce surface roughness, and enhance surface sealing and crusting (Fig. 20), thereby increasing runoff (Wischmeier 1973). As runoff increases, rill and gulley erosion may occur (Figs. 21, 22). Gullies are the most obvious type of erosion by water; however, sheet and rill erosion account for most soil losses on cropland (Hayes and Kimberlin 1978).

In addition to the influence of raindrops and runoff per se , water erosion is also influenced by intensity and duration of rainfall; length and steepness of slope; texture, organic matter content, aggregate stability, roughness and ridging of soil; amount, type, distribution and anchorage of surface residue; and type of erosion control practice (e.g. contouring, strip cropping, terracing). The factors influencing erosion have been extensively studied and reviews and guidelines pertaining to erosion control have been published by FAO (1978b), Hayes and Kimberlin (1978), Kimberlin (1976), Stewart et al. (1975), Wischmeier (1973), and Wischmeier and Smith (1978). The Universal Soil Loss Equation (USLE) is widely used to predict potential erosion by water and to evaluate the effectiveness of various practices to control water erosion. The USLE is

$$A = RKLSCP$$

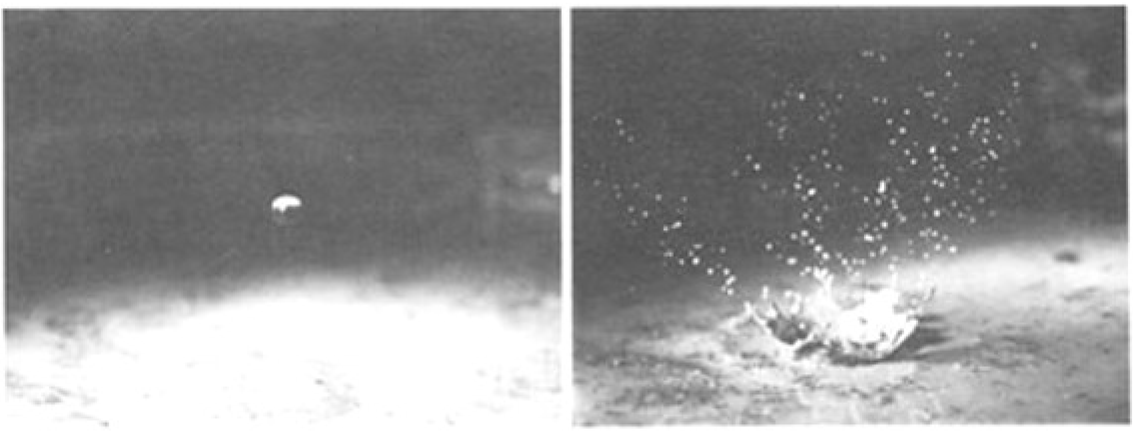


Fig. 18 Falling drop of water (left) impacts soil surface (right), thus loosening and lifting soil particles and contributing to erosion (Naval Research Laboratory photos)

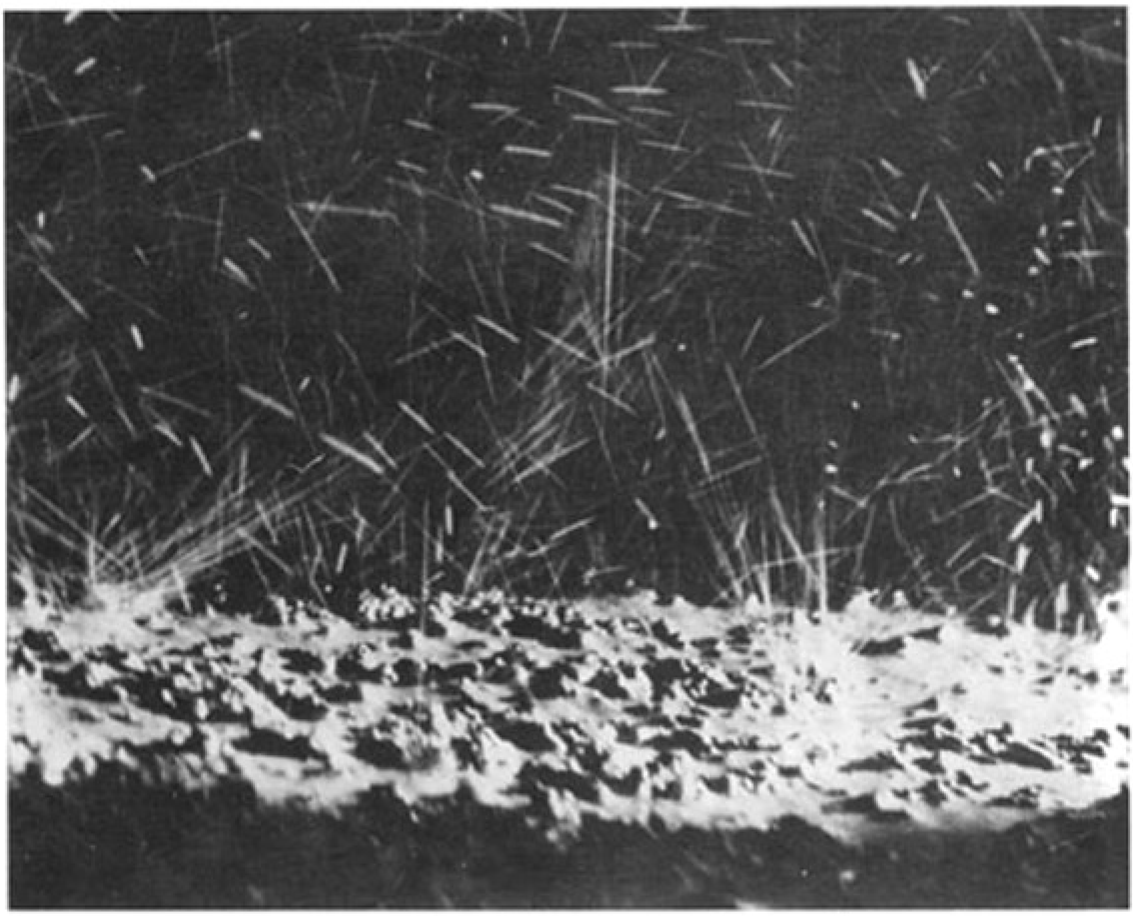


Fig. 19 Intense rain loosens and lifts soil particles, thus contributing to erosion (USDA-Soil Conservation Service photo, issued by FAO)

Fig. 20 Intense rainfall on bare soil causes aggregate dispersion, surface sealing, and high runoff and low infiltration of water

Fig. 21 Rill erosion on wheatland in the Palouse region of Washington (USA). Soil losses may be as high as 40 tons/ha annually with clean tillage methods on such land (photo provided by D.K. McCool, USDA-ARS)

Fig. 22 Gully erosion in the Oued Lallouf hills of Tunisia (UN photo, issued by FAO)

where A is computed soil loss per hectare; R, rainfall factor based on the number of erosion-index units in a normal year's rainfall at a specific location; K, soil erodibility factor; L, length of slope factor; S, slope gradient factor; C, crop management factor; and P, erosion control practice factor. All factors are unitless, except A and K. Units for A are metric tons/hectare (or tons/acre) per year and those for K are metric tons/hectare (or tons/acre) per erosion index unit (Hayes and Kimberlin 1978). Values for the factor's of the equation are available for many conditions at numerous locations (Stewart et al. 1975).

c. Tillage erosion

Soil erosion by tillage, a type of en masse movement (Plaisance and Cailleux 1981), occurs when mouldboard, one-way disk, or similar ploughs are operated in such a manner that the soil is repeatedly turned in one direction. It is most prevalent on sloping soils when such tillage is performed across the slope, but also occurs with tillage parallel to the slope and on level or nearly level fields.

Tillage erosion can be minimized by turning the soil upslope on sloping fields and alternately in opposite directions on level or nearly level fields. Tillage erosion can be further minimized by using implements that do not invert the soil.

ii. Magnitude

Few, if any, of the world's agricultural areas are immune to degradation due to some type of erosion, mainly by wind and water. Although wind erosion is generally believed to be of consequence only in arid and semi-arid regions, it may occur wherever soil, vegetation and climatic conditions occur that are conducive to erosion. The most widespread wind erosion, however, occurs in arid and semi-arid regions where precipitation is inadequate or variable from year to year or season to season to such an extent that a crop or cover of residues cannot be maintained on the land. The general regions most susceptible to wind erosion on agricultural land are much of North Africa and the Near East; parts of southern and eastern Asia, Australia and southern South America; and the semi-arid parts of North America (FAO 1978a).

The amount of soil eroded from a given site during a particular storm or season is highly variable and depends on prevailing conditions. It may be slight and insignificant or may seriously damage or completely ruin a field with respect to subsequent crop production (Fig. 14). Filling of ditches, covering of roads, burial of fences, and removal of all tillage-loosened topsoil are other consequences of wind erosion that have resulted from one or a few storms (Bennett 1939; Constantinesco 1976; Costin 1976; also, personal observations). Where complete removal of topsoil occurred (Bennett 1939), the estimated loss could have been 1400 t/ha, assuming a 10 cm tillage depth and a 1.4 g/cm^3 soil bulk density. Whenever it can be seen that erosion has occurred, the amount of loss undoubtedly is greater than 11.2 metric t/ha (5 tons/acre), the so-called tolerable level of annual erosion often used in United States' literature, because such loss amounts to only about 0.8 mm of soil when it is uniformly removed from the surface and a 1.4 g/cm^3 bulk density is assumed. Even the 11.2 t/ha annual rate, however, results in degradation of some soils, as recognized in recent publications pertaining to soil erosion.

As with wind erosion, water erosion may occur wherever conditions conducive to erosion exist. At some time, nearly all of the world's 6000 million hectares of agricultural land needs some protection from water erosion (FAO 1978b). Even moderate rainfall on bare soil breaks down soil particles and starts the erosion process which can produce serious damage if it is not quickly halted by some erosion control practice. Where rainfall is heavy on cleanly tilled sloping fields, severe damage or complete ruin due to erosion may occur in a short time (FAO 1978b). Consequently, areas most affected by water erosion are those with heavy rainfall and sloping lands. Lands highly susceptible to water erosion include those in much of Africa (except desert regions), South America, Australia and southern Europe, and virtually all southern North America, Central America, southeast Asia, New Zealand, the Caribbean islands and most Pacific islands (Constantinesco 1976).

Tremendous amounts of soil may be eroded from a given land area in a relatively short period, even during a given rain storm. Gullies are the most obvious evidence of erosion and can severely damage or destroy croplands, roads, buildings and other structures. However, sheet and rill erosion undoubtedly are more detrimental to crop production than gulley erosion.

Through sheet and rill erosion, topsoil from the entire field may be lost. This soil is usually the most fertile because it contains plant nutrients, humus and fertilizers that may have been applied (FAO 1978b). Unfortunately, sheet erosion is rather inconspicuous

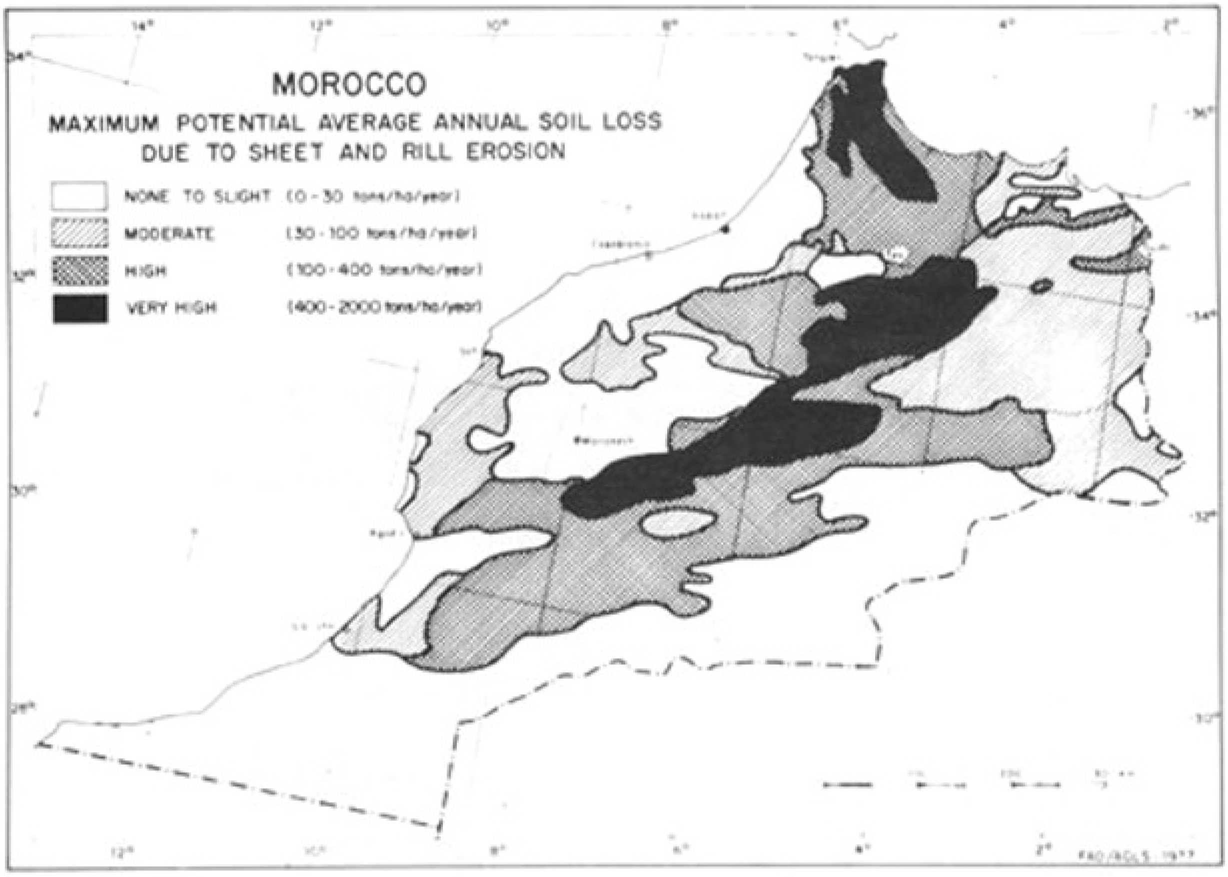


Fig. 23 Maximum potential annual soil loss due to sheet and rill erosion in Morocco (from Arnoldus 1977)

Fig. 24 Extensive erosion caused by deforestation in Colombia (FAO photo)

because it usually removes only a thin layer of soil from a given area during a given storm. Results of continued sheet erosion are often manifest by light-coloured patches of soil or exposed rocks on hillsides. By this time, the soil may have lost much of its productive capacity (FA0 1978b).

While sheet and rill erosion are relatively slow processes, large amounts of soil can be lost under some conditions. Constantinesco (1976) reported that a field in Tanzania lost 50 mm of topsoil over its entire surface during a heavy rainstorm of only a few hours. For some parts of Morocco, the maximum potential average annual soil loss due to sheet and rill erosion is estimated to be between 400 and 2000 t/ha (Fig. 23) (Arnoldus 1977). The estimate was obtained through application of the USLE.

iii. Consequences

Land degradation because of erosion results from the loss of soil more rapidly than it is formed through natural processes. The several centimetres of soil that can be lost in one or a few wind or rainstorms probably represents nature's work for a few hundred or few thousand years (Bennett 1939). Associated with the soil losses per se are losses of the soil's organic matter (or humus), fertility and water-holding capacity. These losses can be overcome, up to a point, through more intense management, increased applications of fertilizers, and more frequent irrigations on irrigated lands. Eventually though, continued erosion cannot be compensated for by increased inputs. When this occurs, production decreases because of lower soil fertility, lower water-holding capacity, and eventual deterioration and complete destruction of the land resource base due to removal of topsoil (and subsoil in extreme cases) and development of gullies (Fig. 24).

The social problems related to uncontrolled erosion depend on the intensity and extent of land degradation. Initially, there is a decline in living standards for the people directly affected by erosion. To maintain production requires increased inputs, often of a monetary nature (Constantinesco 1976), which results in less money being available for other goods and services. As erosion becomes more intense and affects larger areas, food shortages may develop which can lead to civil strife (Figs. 25, 26). To avoid hardships resulting from food shortages, settlements may be abandoned and people may migrate to other regions or countries. In some cases, excessive erosion undoubtedly contributed to the decline or collapse of some early civilizations (Bennett 1939).

As for social problems, economic consequences of uncontrolled erosion also depend on the intensity and extent of land degradation. Producers may suffer economically from destroyed crops, lower yields, and the necessity for increased inputs such as additional fertilizers, tillage for erosion control, tillage or other means of correcting damage due to erosion, and application of other erosion control measures (Constantinesco 1976). As food production declines, food prices usually increase because of the shortage itself or the need to transport additional food from other producing regions. Another economic consequence of erosion can be taxes imposed by public agencies for the purpose of providing information and assistance for installing erosion control measures on agricultural lands.

Three types of problems associated with soil erosion that are difficult or impossible to assess accurately from a social or

Fig. 25 Food distribution in Bangladesh in 1977 (WFP/FAO photo by T. Page)

Fig. 26 Women and children awaiting emergency feeding in Ethiopia (UNICEF photo by Arild Vollan, issued by FAO, Rome)

economic viewpoint concern the health and welfare of humans and animals, the ecology and the environment of the affected areas. Humans and animals in rural areas and even in cities can sometimes suffer serious illness, or even die, due to prolonged dust inhalation (FAO 1978a). Health problems related to nutrition may result from inadequate food, from an imbalanced diet, or from food lacking in essential nutrients. The welfare of humans and animals may be endangered by floods that are intensified because of increased runoff from inadequately protected lands.

Given sufficient time, an ecological balance develops among the factors of climate, soil, vegetation and inhabitants (humans, animals, birds, etc.) of a region. This balance can be maintained indefinitely unless one or more factors exert a disproportionate burden on the other factors, either intentionally or through the forces of nature. Examples include clearing of lands and use of unwise cultural practices that lead to accelerated erosion, over-grazing by animals (domestic and wild), wild fires, and changes in climate. Climatic variability may have a major impact on the ecological balance of a given region during a relatively short period. However, the hypothesis that increasing aridity of the climate over historic times is responsible for the regression of vegetation and decline in agricultural production in such areas as those adjacent to the Sahara in Africa is largely rejected (Le Houérou 1976).

2.1.2 Silt Deposition

Silt deposition is a direct consequence of soil erosion because all eroded materials eventually settle from the air or water. Fortunately, much of the eroded material settles quite rapidly with the rate of settling being dependent, among other factors, on particle size. Unfortunately, the fine, more fertile materials are carried greater distances by wind and water, leaving behind the less fertile, coarse materials.

For materials transported by water, the amount transported depends on the volume and velocity of water flow and on the amount initially eroded. However, all eroded materials do not leave the drainage area. Stewart et al. (1975) roughly estimated sediment delivery ratios for drainage areas of different sizes (Table 1), but they also recognized that soil texture, relief, type of erosion, sediment transport system and areas of deposition within the watershed would all affect the amount of sediment delivered to downstream waters. Although soil texture and relief are

Table 1 INFLUENCE OF DRAINAGE AREA ON SEDIMENT DELIVERY RATIO (from Stewart et al. 1975)

Drainage area		Sediment delivery ratio
km^2	m^2	
1.3	0.5	0.33
2.6	1.0	0.30
13.0	5.0	0.22
26.0	10.0	0.18
130.0	50.0	0.12
260.0	100.0	0.10
518.0	200.0	0.08

Fig. 27 Silt deposited in low area of maize field in the USA. Standing water plus silt destroyed the crop (USDA-Soil Conservation Service photo, issued by FAO)

Fig. 28 Workers removing silt from Solo River in Java, Indonesia. Silt was deposited in the river due to erosion on uplands (FAO photo)

inherent characteristics of a soil and cannot easily be altered by tillage, the type of tillage system and related practices can greatly affect initially the type and intensity of erosion, then the volume and velocity of water flow, thus affecting the amount and distribution of transported sediments. Through proper application of well-designed tillage systems and supporting practices, land degradation due to silt deposition can be virtually eliminated.

Although areas of silt deposition from ages past constitute some of the world's primary agricultural areas, the immediate consequences of silt deposition are usually negative. Depending on the time of occurrence, silt deposition on cropland may interfere with tillage operations and crop establishment, damage or destroy crops (Figs. 12, 27), and destroy or negate the effectiveness of drainage ditches, terraces, waterways and irrigation canals. Besides, it may bury fences and other structures, close roads, bury or damage equipment, clog streams, and fill lakes and reservoirs with sediments (Fig. 28).

All the above consequences of silt deposition usually result in economic losses and a decline in property values. Additionally, deposition of infertile, coarse-textured materials may reduce the productivity and value of cropland, especially if the amount deposited is of such depth that it cannot be removed or ploughed under economically.

When sediments cover fences and roads, clog streams and canals, fill lakes, settle in houses, farmsteads and cities, and damage equipment, the cost of sediment removal or equipment repair can be great. Even greater economic losses may occur, for example, due to greater flood damage if sediments are not removed from streams and lakes. The most economical solution to the silt deposition problem undoubtedly is to minimize or prevent silt transport from source areas through use of effective erosion control and sediment trapping measures.

2.1.3 Desertification and Dune Creep

Land degradation due to desertification and dune creep are closely related to soil erosion, mainly by wind but water may also be a factor. Desertification, according to Dregne (1977), is the process of land degradation that ultimately results in the transformation of productive land into a desert, a process that Le Houérou (1976) called desertification. Le Houérou (1976) gave desertification a broader meaning, namely, the regression of vegetation under arid, semi-arid and even subhumid climates. In either case, however, the final result would be the degradation of land into a desert and, under certain conditions, dune creep could become an associated problem.

Desertification largely results from the influences of man when vegetative cover is reduced or destroyed by allowing overgrazing by livestock, expansion of cultivated land into marginal areas, destruction of woody plants (harvest for firewood, overpruning and lopping of forage trees), poor pasture management (for example, poor spacing of wells for watering livestock), or any other practice that disturbs the natural condition (Dregne 1977; Le Houérou 1976). Wind and water erosion accelerates as the land is degraded, which in turn accelerates the degradation process. When the land has deteriorated sufficiently, it is abandoned. Subsequent recovery may require many years; in extreme cases, degradation may be irreversible (Le Houérou 1976).

This report will not pertain to desertification and dune creep specifically. However, the potentials of tillage systems and related practices for halting or reversing these types of land degradation will be discussed as appropriate.

2.1.4 Salinization and Alkalization

Land degradation due to salinization and alkalization is a long-recognized problem of agriculture in arid and semi-arid regions, both under rainfed and irrigated conditions (Massoud 1980; Richards 1954), and may be a problem also on low lying and poorly drained areas in more humid regions (Richards 1954). Estimates are that almost one billion hectares of the world's soils are currently affected by salts (Szabolcs 1977).

Salinization and alkalization, if excess amounts of sodium are present, are essentially processes of water and solute transport, solution concentration, and salt deposition in or on the soil at the affected areas. The process begins with excess water that moves downslope, either as surface runoff or as percolating water that moves above impermeable or slowly permeable soil layers. The flowing water dissolves or is mixed with salt from the soil or aquifer and becomes brackish or saline. The water and salts accumulate on or rise to the surface at low points or side slopes on the landscape where evaporation further concentrates the salts (Massoud 1980). Unless leaching or drainage are adequate to maintain sufficiently low salt concentrations, crop production may be reduced or eliminated (Fig. 29).

Fig. 29 Complex pattern of saline (dark) and non-saline (light) areas in Iraq (FAO photo)

Because tillage systems and associated practices influence water infiltration, runoff and evaporation, they also influence the salinization and alkalization of soils and the reclamation of saline and alkali soils. The effects of tillage systems and associated practices will be discussed in subsequent sections.

2.2 POTENTIALS FOR CONTROLLING LAND DEGRADATION

2.2.1 Introduction of Appropriate Land Use Measures

The ultimate solution to the land degradation problem is to apply appropriate land-use measures to all land. Under such a programme, for example, crop production would be limited to such areas where erosion is at acceptable levels or where erosion can be maintained at or below acceptable levels through use of effective erosion control practices. Likewise, lands not suitable for crop production would be maintained in permanent ranges or pastures with controlled grazing and use of other suitable management practices, in forests with application of suitable timberland management practices, in wildlife areas, or in other use categories as may be required by the populace.

Before appropriate land-use measures can be introduced, the land resources of a country along with their potentials for use and degradation must be thoroughly understood (FAO 1977a). Although land may be classified for various purposes (Higgins 1977), the suitability or non-suitability of land for crop production is of main concern in this report.

The starting point for evaluating land resources is a field survey which locates and identifies soils by mapping units. For the soil surveys, a land capability classification is then prepared and related to the soil mapping units (Constantinesco 1976). In the system developed by the Soil Conservation Service of the US Department of Agriculture, eight land capability classes are recognized. These classes (Table 2) are based on the suitability of the land for use without permanent damage. In establishing the classes, factors considered were the risks of land damage from erosion and other causes, and the difficulties in land use due to physical land characteristics and climatic factors (SCSA 1982). Other classifications could be based on other types of land degradation (for example, desertification (FAO 1977b) and salinization).

The technology for avoiding or reversing the processes of land degradation is available in many cases. Certainly, improved technology is needed, but until it is developed, existing technology should be used wherever possible.

The importance of wise land use has long been recognized in some countries and regions. Japan, for example, has steep land slopes and loose volcanic soils that are highly susceptible to erosion during torrential rainstorms; but, because of the large population (over 112 million), Japan is compelled to cultivate intensively all its arable land, which is slightly over 6 million hectares. Japan has maintained good agricultural production and resource conservation through use of most of the fundamental erosion-control methods that are essential to the life and economy of .the country. The laws and regulations for such protection are known and heeded by all people in Japan who are involved in using the land (FAO 1978b).

Another country that has recognized the importance of protecting its steeply sloping, fragile soils against erosion is Malaysia. Whenever land is cleared for any purpose, Malaysian laws and regulations require that an effective cover crop or other protection against erosion by established within a few days (T.F. Weaving, FAO, Rome, personal communication).

A region noted for its low level of soil erosion is central and northern Europe. While rainfall intensities in that region are not as high as in many others, the people of the countries in that region have long recognized the value of wise land-use measures and readily support the government-decreed land-use policies. In those countries, crops are grown only on land suitable for cultivation, and grasslands and forestlands are on landscapes suitable for those purposes (F.W. Hauck, FAO, Rome, personal communication).

Table 2 LAND CAPABILITY CLASSES (SCSA 1982)

Class	Description
	SUITABLE FOR CULTIVATION AND OTHER USES
I	Few limitations that restrict their use
II	Some limitations that reduce the choice of plants or require moderate conservation practices
III	Severe limitations that reduce choice of plants or require special conservation practices, or both
IV	Very severe limitations that restrict the choice of plants, require very careful management, or both
	LAND LIMITED IN USE - GENERALLY NOT SUITED FOR CULTIVATION
V	Little or no erosion hazard, but have other limitations that are impractical to remove and that limit their use largely to pasture, range, woodland, or wildlife food and cover
VI	Severe limitations that make them generally unsuited for cultivation and limit their use largely to pasture or range, woodland, or wildlife food or cover
VII	Very severe limitations that make them unsuited for cultivation and restrict their use largely to grazing, woodland, or wildlife
VIII	Limitations that preclude their use for commercial plant production and restrict their use to recreation, wildlife, water supply, or aesthetic purposes

Unfortunately, implementation of wise land-use policies and existing technology is often thwarted by lack of awareness or indifference to the problems, or due to lack of adequate economic incentives (Rauchkolb 1971). Social and political factors may also be involved. To gain more widespread acceptance of measures for controlling land degradation, a comprehensive programme of education, organization, manpower training and extension work is required. Also, social, political and economic factors will need to be considered (Carpenter 1980; Fosbrooke 1974; Le Houérou 1976).

2.2.2 Tillage

The ultimate aim of tillage is to change a soil from a known initial condition to a different desired condition by mechanical means (Gill and Vanden Berg 1967). For crop production, this aim would be to provide a soil environment for improved plant growth and production, and would be applicable where appropriate land-use measures are employed and where tillage is considered to be a means for controlling land degradation.

The specific objectives of tillage vary widely and depend on such factors as soils, climate, crops to be grown, and prevailing conditions. Some commonly given advantages for tillage include weed control; soil and water conservation; insect, disease, and rodent control; soil structure improvement (disrupting plough soles and other dense layers); fertilizer, herbicide and plant residue incorporation; soil nutrient mineralization; seedbed preparation; and crop yield improvement or stabilization.

The foregoing and some other qualitative advantages for tillage are grouped in Table 3 under seven objectives of clean tillage that were identified by Gill and Vanden Berg (1967). Because tillage may also adversely affect soil conditions and other factors related to crop production, some disadvantages are included in Table 3. The generalized disadvantages are based on clean tillage relative to conservation tillage systems that involve the maintenance of surface residues. Also, a tillage advantage under one condition or one soil may be a disadvantage under another condition or on another soil. Therefore, a thorough understanding of tillage effects is essential for wise application of tillage for crop production in general and for soil and water conservation in particular in a given situation.

2.2.3 Practices Related to Tillage

Wise use of tillage practices is usually adequate for conserving soil and water resources on lands comparable to those recognized as Class I in the US system (Table 2). As land slopes and climatic limitations increase, practices that complement tillage methods are required to prevent land degradation due to erosion. Some practices, which actually become an integral part of the tillage system, include contouring, use of graded furrows, terracing, strip cropping, basin listing, land levelling, mulching, following, use of rotations, use of cover crops, and irrigation. These will be discussed in more detail in a later section.

2.2.4 Alternate Practices

On lands with moderate, severe, or very severe limitations with respect to suitability for crop production (Table 2), practices are usually required which result in some of the land being removed from crop production. However, some lands, with careful management, may still be used for grazing, hay and tree production. Practices that usually result in some land being removed from crop production include diversion terraces, waterways, water harvesting, runoff farming, windbreaks, sand and silt traps, and desert pavement. These practices, at least to some extent, have potential for conserving soil and water resources and thus controlling land degradation when used in conjunction with other effective conservation practices.

Table 3 QUALITATIVE OBJECTIVES, ADVANTAGES AND DISADVANTAGES OF SOIL TILLAGE IN RELATION TO CROP PROIDUCTION

Objective	Tillage action	Advantage	Disadvantage
Soil conditioning	Cutting, loosening, granulating	Weed control, water conservation, structure improvement, seedbed preparation, better drying of wet soils	Greater erosion potential, high energy input , increased evaporation
Eradication or control of plants or plant materials	Cutting, inverting, mixing	Weed control, volunteer plant control, water conservation, establish desirable plant populations, pest control[2], better drying of wet soils, mineralization of soil nutrients	Greater erosion potential, may cause compaction, high energy input1, decreased soil organic matter, increased evaporation
Establishing soil boundaries and surface configurations	Cutting as with coulters to improve ploughing operation, land forming	Weed control, soil conservation, water conservation, residue incorporation, seed-bed preparation, better drying of wet soils, warmer soil temperatures	Greater erosion potential, may cause compaction, high energy input, increased evaporation
Incorporating, covering, or handling foreign materials	Cutting inverting, mixing	Weed control, residue incorporation, mineralization of soil nutrients, fertilizer and pesticide incorporation, pest control better drying of wet soils, warmer soil temperatures	Greater erosion potential, may cause compaction, high energy input, decreased soil organic matter, increased evaporation
Segregation	Move soil materials from one layer to another	Wind erosion control, better drying of wet soils	High energy input, increased evaporation
Mixing	Mixing	Better drying of wet soils, improved soil amendment distribution, fertilizer and pesticide incorporation, soil texture improvement (mixing of two or more layers), soil structure improvement, mineralization of soil nutrients	Great erosion potential, high energy input, decreased soil organic matter, increased evaporation
Compaction or firming	Rolling or pressing	Improved seed-soil contact	May cause compaction

1 High energy input - may include fuel for tractors, feed for animals, labour and equipment inventories or usage.

2 Pests controlled may be insects, diseases, rodents, etc.

3. TILLAGE SYSTEMS

Some form of tillage system is involved in the production of all crops. It may be as simple as punching or digging holes in soil to plant seeds, seedlings, tubers, or other means of plant propagation, then controlling competing plants by hoeing or slashing. On the other hand, it may be a highly complex system involving primary tillage, several subsequent tillages, application of fertilizers and pesticides (includes herbicides, insecticides, etc.), and the planting operation. After plant establishment, additional operations may be used to control weeds, control erosion, or break surface crusts to enhance soil aeration or water infiltration.

Between the above extremes, an infinite variety of systems have been or are being used to produce the world's supply of foods. Seldom do two producers, even within the same geographic region, use exactly the same practices with respect to such factors as type, time, depth and speed of operation. Each producer has essentially his or her own tillage system. A discussion of such seemingly endless variety of systems is beyond the scope of this report. However, some generalized tillage systems have been developed and these will be discussed relative to their effect on the conservation of soil and water resources and on crop production.

3.1 SELECTION OF TILLAGE SYSTEM

The tillage system selected for a particular situation depends on such variables as climatic zone, crop to be grown, soil factors, economic level of the producer, preferences of the producer, social influences, and government policies. No variable is entirely independent of the others; hence the seemingly endless variety of systems previously mentioned. Each variable, however, will be discussed in relation to its effect on the selection of tillage system and, in turn, on soil and water conservation.

3.1.1 Climatic Zone

The climatic factors that have a major influence on selection of tillage systems are precipitation, temperature, radiation and wind. The amount and distribution of precipitation are undoubtedly the most important by themselves but they also affect the temperature, radiation and, to some extent, wind movement in a given region.

i. Precipitation

In precipitation-deficient regions, tillage systems and related practices for conserving water are highly desirable because as much water as possible must be stored in soil for subsequent use by plants (Fig. 30). To achieve this, tillage systems or practices that enhance water infiltration, trap snow, and suppress subsequent evaporation are desirable. Enhanced infiltration may be achieved by reducing runoff rates, maintaining a soil surface condition conducive to rapid infiltration (Fig. 31), and removing or disrupting soil profile layers that restrict water penetration. Reduced evaporation can be achieved by deeper storage of water within the root zone and by improving the microclimate at the soil-air interface. The microclimate can be improved by using practices that maintain mulches (for example, crop residues) on the soil surface to intercept or reflect incoming radiation, provide surface roughness to reduce windspeeds, and avoid high soil temperatures.

Another goal of tillage in precipitation-deficient regions is to

Fig. 30 Farmer in Brazil amid plants that are badly in need of water. Use of improved practices for water conservation could reduce adverse effects of drought (FAO photo)

Fig. 31 Straw left on the surface by non-inversion tillage increases water absorption and helps control wind and water erosion (FAO photo)

maintain or reduce soil erosion to tolerable levels. Water and wind erosion may be major problems in these areas. Practices that enhance water infiltration and reduce the rate of runoff aid in controlling water erosion. For wind erosion control, practices that maintain residues on the surface or provide a roughened surface (clods, ridges) are desirable (Fig. 31).

In regions where precipitation is abundant or excessive, use of grassed waterways that harmlessly convey excess water from the land is desirable. However, a prime requisite should be to store adequate water in the soil for favourable plant growth and development during the short-term droughts* that sometimes occur in these humid areas. Where excess water is a lingering problem, drainage may be required as part of the overall system. Where it is an occasional problem (for example, near or at planting time), ridging or ploughing to expose wet soil or removal of surface residues may be used to hasten soil drying and, thus, overcome excessive soil wetness.

ii. Temperature

The prevailing temperatures strongly influence crop adaptation in a region (Wilsie 1962). In tropical and subtropical regions, crops are seldom adversely affected by low temperature limitations. However, where the frost-free growing season is relatively short, a few extra days of growing season can make it possible for a crop to mature before frost and thus make better use of prevailing water supplies for crop production. Tillage systems have little or no effect on air temperatures, but can be used to manipulate soil temperatures so that crops can be planted earlier, thus extending the growing season.

In the northern United States, Radke (1982) showed that maximum seedbed temperature occurred either under the peak or on the southerly exposed slope of ridged soil. A surface mulch decreased daytime soil temperatures, but a combination of mulching and ridging resulted in similar soil temperatures under the mulched ridge as those in conventionally (clean) tilled soil without a mulch. The combination of mulching and ridging, which is a tillage effect, provided a means of managing soil water and temperature in the seedbed, thus improving the use of conserved water and providing protection against erosion.

In warm climatic zones where low temperatures are rarely a problem, lower temperatures under surface residues in summer, or at any time in extreme cases, may beneficially influence crops growing during hot periods (Allen et al. 1975; Rockwood and Lal 1974). .

iii. Radiation

Tillage affects the radiation balance (absorption, heat storage, reradiation) of a soil mainly through its effect on soil colour and water content (Wilsie 1962), slope relative to the sun and surface residues (Radke 1982; Van Doren and Allmaras 1978). Light-coloured surfaces reflect radiation whereas dark ones absorb it (Wilsie 1962). Thus a freshly tilled, rough moist soil will absorb more radiation than a smooth, dry soil. On sloping soils, absorption is greatest when the sun is perpendicular to the slope (Radke 1982).

The radiation balance due to surface residues is affected by the colour, age and geometry of residues. Bright residues reflect a large percentage of the incoming radiation. As residues age and darken, reflectance decreases. Reflectance is also lower for standing residues, which cause shadows, than for flattened ones (Van Doren and Allmaras 1978). The radiation balance has a direct effect on photosynthesis (Wilsie 1962). It also indirectly affects water conservation through its effect on soil temperature (Radke 1982; Van Doren and Allmaras 1978),

iv. Wind

Windspeed and, to some extent, wind direction have a major influence on tillage systems most suitable for a given climatic zone, mainly because of the potential of different tillage systems for controlling wind erosion. On soils subject to wind erosion, tillage systems that maintain surface residues or provide a rough, cloddy, or ridged surface during the windy season should be used (Fig. 31). Where winds from one direction predominate, the direction of tillage operations that ridge the soil surface should be perpendicular to the prevailing winds (Massoud 1975). On soils where the wind erosion potential is much greater than the water erosion potential, soil-ridging tillage should be done perpendicular to the prevailing winds rather than on the contour. While contour tillage would control water erosion, wind blowing parallel to the ridges could cause far greater erosion than that caused by water during infrequent rainstorms. This would be especially true on deep sandy soils having relatively high water infiltration rates.

3.1.2 Crop to be Grown

The world’s agricultural literature is replete with reports pertaining to the effects of various tillage methods or systems on crop production. Many of the reports pertain to a particular crop. Unfortunately, the effects of tillage systems on soil conditions per se were often not evaluated. Differential crop responses were frequently the result of such tillage-induced differences as soil water content, weed control, aeration, root zone depth, and fertility rather than the tillage method or system per se.

Because crops differ in their requirements relative to such tillage-induced conditions as listed above, a tillage system providing a particular condition would be the most appropriate for a given crop. For example, the response of fibrous-rooted grain crops (wheat[1] and sorghum for grain) was related to the amount of water available for1 crop use (Eck and Taylor 1969; Unger 1969, 1972; Unger et al. 1973; Unger and Wiese 1979) and little affected by soil physical conditions resulting from tillage methods. In contrast, a root crop such as sugarbeet responded to tillage=induced increases in water infiltration as well as decreases in bulk density and increases in aeration in a dense clay loam soil (Mathers et al. 1971).

Tillage systems that provide a specific soil condition may also be required for some other groups of crops. These include (1) a deep, loose root zone for tuber and root crops, (2) a uniform, finely granulated seedbed for small-seeded crops requiring precision planting, and (3) a trash-free surface for short-statured crops for which trash would interfere with harvesting operations or lower crop quality (for example, vegetables and cotton). Unless some other factor is adversely affected, the desired condition can usually be achieved by any of several tillage operations.

3.1.3 Soil Factors

Soil factors that are of importance relative to the selection of tillage systems include soil slope, texture, depth, density, salt or alkali content and drainage. In all cases, tillage selection based on soil factors should consider the interacting effects of the climatic zone and crop to be grown.

i. Slope

On nearly level or gently sloping soils, many tillage systems provide the desired conditions and effectively conserve the soil and water resources. As slopes increase, the choices become more limited. A conservation tillage* system that maintains surface residues is best suited for water erosion control on sloping soils when other supporting practices are not used. When supporting practices such as contouring, terracing and strip cropping are used, somewhat greater latitude in choice of tillage systems is possible. Land levelling permits the use of almost any type of tillage system. However, on steeply sloping soils, the levelled areas become extremely narrow and, therefore, the use of some tillage methods or systems may be impractical (Figs. 32, 33). Tillage may even be restricted to use of hand implements on such areas.

Fig. 32 Terraced rice fields, Luzon (FAO photo)

ii. Texture

Soil texture has a major influence on a soil's susceptibility to erosion and, therefore, on the selection of tillage methods or systems for controlling erosion. Conservation tillage systems, as a rule, are highly effective for controlling wind and water erosion on soils of all surface textures (Harrold and Edwards 1972, 1974; Hays

Fig. 33 Terraced land north of Taipei, Taiwan (photo by Helen and Frank Schreider, copyrighted by National Geographic Society, January 1969)

Fig 34 Relatively smooth surface (left) resulted from disk tillage and rough surface (right) from chisel tillage. Water infiltration was much better on the rough surface which was also effective for controlling wind erosion (photo provided by T.F. Weaving, FAO, Rome)

1961; Onstad 1972; Skidmore and Siddoway 1978; Wischmeier 1973; Woodruff and Siddoway 1973). They are also effective for conserving water on most soils (Barnett et al. 1972; Harrold and Edwards 1972; Hays 1961; Onstad 1972; Rockwood and Lal 1974; Unger et al. 1971; Unger and Wiese 1979).

On sandy soils susceptible to wind erosion where few if any crop residues are available, lister or chisel ploughs rather than mouldboard or disk ploughs should normally be used. To be effective, the tillage must be performed perpendicular to the prevailing winds and at a soil water content conducive to forming a rough surface. Clods should not be pulverized (Massoud 1975). Mouldboard ploughing is sometimes nsed on sandy soils to bring finer textured materials to the surface to aid in forming clods and, thereby, reduce the potential for erosion.

The choice of tillage method or system is greater on finer textured soils for controlling wind erosion (Lyles and Woodruff 1962; Woodruff et al. 1965; Woodruff and Siddoway 1973). The major prerequisite of any tillage system for controlling wind erosion where surface residues are not available is to produce a rough cloddy or ridged surface (Fig. 34). About 75 percent of the surface soil material should be greater than 0.84 mm in diameter to hold annual soil losses due to wind erosion to less than 11.2 t/ha on large, bare, smooth, unprotected fields (Woodruff and Siddoway 1965).

Effective control of water erosion on soils of all textures, when limited amounts or no surface residues are present, usually depends on the use of supporting practices such as contouring, terracing, strip cropping, and crop rotations in conjunction with the tillage system. Contouring and terracing reduce slope gradient and length, and hold potential runoff water on the land. Strip cropping, depending on the crop in the strip, reduces runoff velocity and traps sediments. Crop rotations result in part of the land area being in crops that provide protection against erosion. When these areas are then ploughed, the residual effects of water-stable aggregates and root channels, for example, provide for less soil dispersion, less surface sealing and greater water infiltration, and, therefore, less runoff and concomitant erosion.

The tillage method or system itself, however, also affects erosion control on soils with little or no surface residues. In general, best control is obtained with tillage that maintains an unsealed soil surface and permits high water infiltration rates. For this purpose water-stable aggregates are desirable and normally result from maintaining as much organic material as possible at or neae the soil surface.

When precipitation rates exceed infiltration rates, temporary surface storage of water reduces runoff and aids in erosion control. Ridge-forming tillage on the contour is a long-proven runoff control and water conservation practice (Dickson et al. 1940; Fisher and Burnett 1953; Harrold and Edwards 1972). Runoff was eliminated by using lister ploughing (Figs. 35, 36) on the contour in conjunction with closed-end level terraces (Fisher and Burnett 1953) or by basin listing (Figs. 37, 38) gently sloping land (Clark and Jones 1981). Basin listing prevented runoff from an 11.4 cm rainstorm in a 24 hour period on a slowly permeable soil in Texas (USA) in 1978 (Clark and Jones 1981). For subsequent temporary storage on the surface, water collected behind the ridges or dams must infiltrate before the next precipitation event.

Fig. 35 Clean tillage on the contour with a lister plough in Israel (FAO photo)

Fig. 36 Lister ploughing a field after wheat harvest. The attached planters could be used to seed a crop in conjunction with the tillage operation

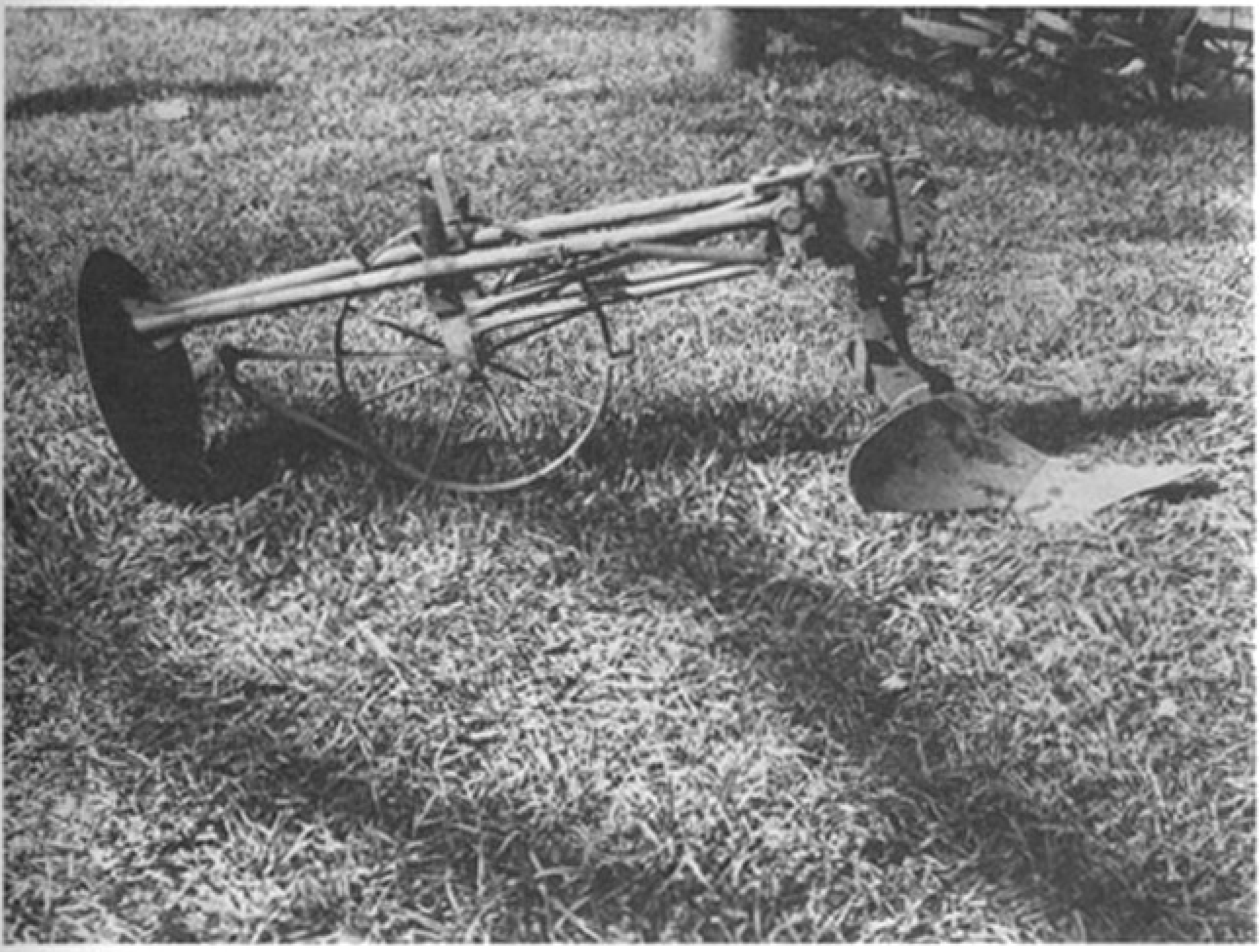


Fig. 37 Basin lister in Uganda (FAO photo)

Fig. 38 Water from precipitation in basin-listed furrows on the contour (photo provided by O.R. Jones, USDA-ARS)

Fig. 39 Stubble mulch tillage with sweep equipment

In contrast to lister ploughing on the contour for row crops, sweep (Fig. 39) and one-way (Fig. 40) ploughing on the contour for winter wheat had little effect on water conservation and yield as compared to such ploughing without regard to slope (Finnell 1944). Apparently, these tillage methods provided similar surface roughness and porosity, regardless of slope.

Different tillage methods, however, result in different surface conditions with respect to pore space and roughness, and, therefore, affect runoff (Larson 1962) and the potential for erosion. Burwell et al.(1966) evaluatecd the effects of porosity and surface roughness resulting from several tillage methods on the infiltration of simulated

Fig. 40 One-way disk plough (photo provided by C.R. Fenster, University of Nebraska)

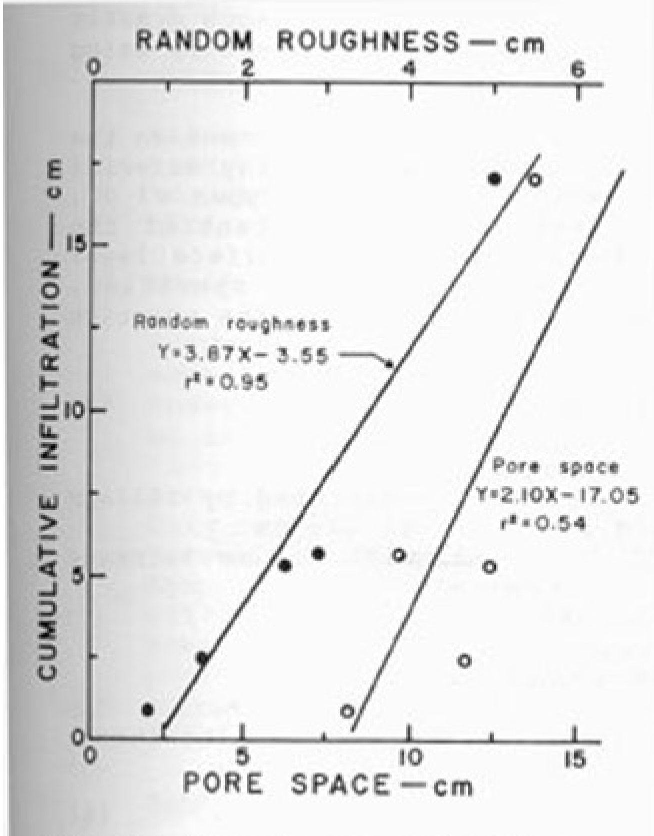


Fig. 41 Effect of soil random roughness and pore space on cumulative infiltration (adapted from Burwell *et al.* 1966)

rainfall (Table 4). Cumulative infiltration approached the total pore space and surface roughness retention volumes for the plough treatment before runoff started and exceeded the total volumes before 2.5 cm of runoff occurred. The potential storage volume was not filled for other treatments, even though 5.0 cm of runoff was measured. Cumulative infiltration before initial runoff was more closely related to surface roughness than to total pore space (Fig. 41). The smoother surfaces with treatments other than ploughing apparently resulted in more rapid surface soil dispersion and sealing, which reduced infiltration into the tillage-loosened soil.

Some sandy soils have a surface layer that has low water-holding capacity, low fertility, and high wind erosion potential. When such surfaces are underlain by layers of fine-textured materials, they can be improved by ploughing to depths that bring the fine materials to the surface. By ploughing 25 to 40 cm deep, Harper and Brensing (1950) increased the clay content of the surface layer and crop yields. Such deep ploughing could decrease water infiltration if too much clay is placed in the surface layer. However, at least 8 percent clay is needed in the surface layer of sandy soils for subsequent tillage to result in clods that resist wind erosion (Harper and Brensing 1950).

Table 4 EFFECT OF TILLAGE-INDUCED PLOUGH LAYER POROSITY AND SURFACE ROUGHNESS ON CUMULATIVE INFILTRATION OF SIMULATED RAINFALL (from Burwell et al. 1966)

Tillage Treatment[2]	Surface conditions: Pore space[3]	Surface conditions: Roughness	Cumulative infiltration1: To initial runoff	Cumulative infiltration1: To 2.5 cm runoff	Cumulative infiltration1: To 5.0 cm runoff
	cm	cm	cm	cm	cm
Untilled	8.1	0.8	0.9	2.1	2.4
Plough	13.7	5.0	17.1	21.7	23.0
Plough-disk-harrow	12.4	2.5	5.3	7.3	8.4
Cultivated	9.7	2.9	5.7	8.3	9.1
Rotovated	11.7	1.5	2.4	3.8	4.1

[1] Water applied at a 12.7 cm/hour rate.
[2] Ploughing and rotovating performed to a 15 cm depth; cultivating to a 7.5 cm depth on otherwise untilled soil.
[3] Measured to the tillaqe depth.

Increased clay content alone may not be the solution to the wind erosion problem on sandy soils. When Chepil et al. (1962) deep-ploughed a sandy soil in Texas (USA), the clay content of the surface layer was increased from 4 to 14 percent. After 5 years, the clay content had decreased to 4 percent again because wind erosion during the period had removed or covered the clay. When such drastic measures are used, their effectiveness should be maintained by using good supporting practices.

The tillage depth required to obtain a desirable clay content in the surface layer of an initially sandy soil underlain by clay material can be calculated by Eq. [3], which was developed by Unger et al, (1981). To apply the equation, the initial clay content of the surface and subsurface layers and the depth of the surface layer must be known, and the desired clay content must be specified. Thorough mixing of the entire tillage layer is assumed. The equation is:

$$(Ad \times A\%c) + (Bd \times B\%c) = (Cd \times C\%c) \qquad [3]$$

where: Ad = depth of surface layer (known)
Bd = depth of subsurface layer to be penetrated by tillage operation (to be solved for)
Cd = depth of ploughed soil (Ad + Bd, with volume increase ignored)
A%c = percent clay in surface layer (known)
B%c = percent clay in subsurface layer (known)
and C%c = percent clay in ploughed soil (specified)

Substituting (Ad + Bd) for cD and rearranging Eq. [3] results in:

c)

$$Bd = \frac{Ad\ (C\%c - A\%c)}{(B\%c - C\%c)} \qquad [4]$$

After solving for Bd, the tillage depth is obtained from:

$$Cd = Ad + Bd \qquad [5]$$

These equations illustrate the technique for determining tillage depths based on soil clay content. For soils having high silt or silt and clay contents in the subsurface layer, similar equations could be developed if the consideration of silt content were important.

iii. Depth

Selection of tillage systems based on soil depth is mainly concerned with the depth to an untillable layer (for example, bedrock) or depth to a layer that would contribute undesirable substances to the tillage zone if mixed with that layer. Undesirable substances include sand, gravel, rocks, high calcium materials, saline or alkali materials, or strongly acid materials.

On shallow soils or soils having undesirable materials near the surface, non-inverting tillage should be used to minimize damage to equipment or the danger of contaminating surface soil with the undesirable substances. Rolling-type equipment, such as disk harrows or ploughs and disk-opener planters are generally well-adapted for use on shallow soils underlain by rocks. Disk tillage, however, may not be desirable because of its tendency to accelerate erosion (Fig. 16). Other types of equipment suitable for such shallow soils are trip-action sweep and chisel implements.

Under shallow soil conditions, a conservation tillage system involving minimum soil disturbance, such as use of herbicides for weed control and a disk-opener planter, would be most desirable. Any tillage system that provides the desired soil condition and still conserves soil and water resources can be used on deep soils.

iv. Dense horizons or layers

Selection of tillage system has a major influence on water infiltration, erosion potential and crop production on soils having dense horizons or layers in the profile. The restricting layer may be a hardpan*, fragipan*, plough sole (or pan)*, naturally dense horizon, or a compact zone resulting from tractor, implement, or animal traffic.

Hardpans involving rock layers are usually not disrupted, except in some large-scale, highly intensive operations (Unger et al, 1981). However, some soils with fragipans, plough soles, or dense horizons or layers can be improved by deeper-than-normal ploughing, chiselling, or mixing of profile layers (Bradford and Blanchar 1977; Burnett et al. 1974; Burnett and Hauser 1967; Campbell et al 1974; Doty et al. 1975; Eck et al. 1977, Eck and Taylor 1969; Musick and Dusek 1975; Patrick et al, 1959; Saveson and Lund 1958; and others). Response to these operations was usually greatest when performed with the soil relatively dry. Disrupting the dense zones permitted greater water infiltration and conservation, and greater root penetration and proliferation to extract water from a larger soil volume.

v. Alkali or salt content

Water conservation and subsequent crop yields were increased on some alkali- and salt-affected soils when added gypsum was mixed with soil or when the soil was ploughed deep enough (to a 60 cm depth) to mix naturally occurring gypsum with the surface layer (Cairns and Bowser 1977; Rasmussen et al. 1964; Sandoval 1978; Sandoval et al. 1972). The benefits resulted from greater water infiltration, root proliferation and, apparently, leaching of harmful materials. Inverting or mixing tillage methods usually gave the greatest benefits with respect to improving water infiltration and crop yields on alkali- or salt-affected soils.

vi. Drainage

Where excess water is a problem, a tillage system which aids in removal of the excess water should be selected. Usually, tillage that maintains surface residues is not desirable because the residues retard soil drying. Conservation tillage (for example, no-tillage) caused lower crop yields on some naturally poorly drained soils in Ohio (Van Doren et al. 1976).

3.1.4 Economic Level of the Farmer

Except for some quick-growing vegetable crops that require only about 20 to 30 days from planting to harvest, most crops require considerably more time and, therefore, represent a long-term investment on the part of the producer. The period from planting to harvest is often 3 to 4 months, and even longer for some crops; in addition there is the time involved for land preparation. During this whole period, some or all of the producer’s resources, depending on the diversity of crops grown, are invested in the production of the crop. The investment may include the labour expended and the cash outlay for fuel, fertilizers and seed. Certainly, the amount of cash or goods of economic value will have a strong influence on the amount of resources expended for crop production, which will influence the type of tillage system and related practices used (Constantinesco 1976).

The major input for crop production by the subsistence farmer is labour. Seed may be saved from the previous crop, traded for, or purchased. Rarely, however, will the subsistence farmer expend cash for other production inputs. Consequently, tillage implements and systems are quite simple.

Except for land clearing and some preplanting weed control by burning or hand labour, little or no other soil preparation is done by the subsistence farmer before the crops are sown, usually by broadcasting the seeds (Fosbrooke 1974; Moody 1974). Weeds in the crop are controlled by hand, either by pulling, hoeing, or slashing. Use of ploughs, if they were affordable, would not normally be practical because crops are seldom planted in rows and because tree stumps and roots would interfere with the ploughing operation on cleared forest lands (Moody 1974). Likewise, use of herbicides for weed control is not practical because crops are frequently interplanted or else planted close together, which makes it impossible to treat weeds chemically in one crop without adversely affecting another. The high cost is another factor limiting the use of herbicides by subsistence farmers (Moody 1974).

Under improved economic conditions, lands for crop production are usually more intensely prepared and subsequently managed during the growing season than under subsistence farming conditions. With respect to tillage, the land is cleared of tree roots and stumps, if necessary, so that it can be ploughed for weed control and seedbed preparation. Planting in rows allows subsequent inter-row cultivation for weed control; however, hand hoeing may be needed to control weeds within the row unless herbicides are used. In many situations, use of herbicides is more economical than use of labour. Where labour is short, herbicides may be used for controlling weeds that cannot be restrained by tillage.

A wide range of tillage systems can be selected from, when economic conditions are favourable for the producer. Depending on a farmer’s economic level, tillage and other cultural operations (planting, weeding, etc.) may be performed by hand, with rather simple implements drawn by animals, or by a variety of different implements drawn by tractors. Tractor sizes vary widely and will influence the type and intensity of tillage performed. Many practices may be combined ranging from conservation tillage systems with little soil manipulation to very intensive systems involving numerous tillage and related operations.

For optimum soil and water conservation, regardless of economic level, the tillage system employed should be based on the prevailing climatic, crop and soil factors previously discussed. Unfortunately, the potential for short-term economic gains often results in the use of tillage systems that are not conducive to long-term conservation of soil and water resources. Unless producers know and understand the long-term benefits of using sound conservation measures, it is doubtful that these measures will be adopted if there is not an immediate economic benefit. This is especially true for the low-income producer and is aggravated by such factors as limited farm size, land availability, land tenure or ownership, land productivity, and availability of suitable conservation measures (Constantinesco 1976).

3.1.5 Preference of the Farmer

Production practices, including tillage systems, may vary widely among producers growing the same crop in a given area. While economic factors undoubtedly are involved, another factor contributing to the diversity of systems used is the preference of the producer. This preference, in turn, may be the result of such factors as upbringing, education, pressure from neighbours or peer pressure, and ambitions.

Farming has long been a family enterprise with heirs assuming the responsibilities from their ancestors, so they tend to employ systems similar or identical to those of their parents. Some of these systems effectively conserve resources; others do not. Where improved systems are needed, these can be learned through extension activities or formal education. Through education, producers can learn the value of sound conservation measures, how to apply them, how to manage and maintain them, and how to manage crops on areas where the conservation measures are used. Because of differences in upbringing and education, it is readily apparent why different producers employ different tillage systems to grow the same or similar crops.

In some countries or regions, tradition plays a major role in the type of tillage system selected. For example, clean tillage was or is regarded as the trademark of the successful farmer in many parts of the USA. The adoption of conservation tillage systems involving the maintenance of crop residues on the soil surface brought with it the derogatory term of “trash farming” by other producers. Such stigma and associated pressures by neighbours can make producers reluctant to accept new or unusual crop production practices. Peer pressure, when properly directed, can also accelerate the acceptance of improved conservation measures.

Farmers who recognize the long-term value of using sound conservation measures will frequently employ one or more such measures in their crop production system. More ambitious producers readily adopt newly developed tillage methods or systems and if they prove unsuitable or not to their liking, they may, through personal ingenuity, develop improved systems or modify existing systems for adaptation to their particular crop production enterprise. Such ambitious producers are not bothered by stigmas and peer pressures, and are often the leaders in getting new systems adapted in a given region.

3.1.6 Social Influences

Social influences on crop production systems are vast and varied, and may result in land degradation on the one hand and resource conservation on the other. The social factor probably most responsible for land degradation is the rapidly increasing world population. Others include ownership of large herds of animals (cattle, sheep, goats, etc.), tolerance of or failure to control animals not contributing to the food supply, emphasis on production of land-degrading crops, and the introduction of practices that are not suitable or practical for use in a developing country. Resource conservation can be achieved when society recognizes its value and, through local action groups, provides incentives for adoption of such practices or penalties for non-adoption.

Increasing population pressures have resulted in land being cropped more frequently in many countries where use of long fallow periods was the common practice (FAO 1978b; Fosbrooke 1974; Lal 1979). Direct consequences of reducing the length of or eliminating fallow periods, often without implementation of soil conserving practices, have been a decline in soil fertility and crop yields (with or without erosion), and even food shortages (FAO 1978b; Fosbrooke 1974). In extreme cases, famine relief or resettlement to an unruined area, if available, is required (Fosbrooke 1974).

In some countries, the wealth of a farmer is indicated by the number of animals (cattle, sheep, goats, etc.) owned; they provide food for the producer and his family, and excess products may be sold. However, excessively large herds place an extra burden on the land and lead to accelerated land degradation (Fosbrooke 1974; Le Houérou 1976). Where large herds are kept, overgrazing often occurs and all crop materials may be harvested as forage for the livestock (Fig. 10). Removal of all residues prevents soil and water conservation through residue management. Overgrazing and high demands for crop residues also result from tolerance of free-roaming animals for religious reasons; excessive populations of wild, tame or pet animals protected by law, in game preserves, or maintained by individuals; and excessive numbers of wild animals (for example, rabbits (Gillespie 1981)) that are not protected, but which are difficult to control.

The basic goal of the subsistence farmer, as previously mentioned, is to provide the family with a stable supply of food. After meeting this need, and if markets are available and other conditions are favourable, the producer will normally grow some products for sale. Within limitations imposed by soils and climate, the crop grown will have the greatest potential for economic return, which in turn is influenced largely by consumer preferences. Frequently, crops grown and tillage and production system used are not conducive to soil and water conservation. Some examples include growing grain crops continuously (with clean tillage and without soil improving crops in rotation); growing cotton continuously on soils highly susceptible to wind erosion (with clean tillage methods); and growing other low residue producing crops such as soybeans, sugarbeets and groundnuts, often by clean tillage methods, on soils susceptible to wind and water erosion.

The need to use improved crop production practices to halt land degradation has long been recognized, and many attempts have been made to introduce such systems. However, this is frequently recognized by those not actually engaged in crop production, but not by the producer. When improvement programmes have been introduced under such conditions, the result often has been failure at the producer level (Carpenter 1980; Fosbrooke 1974).

For satisfactory introduction and adoption of improved practices by the producer, he must be made aware that they are necessary (Fosbrooke 1974). The required changes may involve adoption of tillage systems and related practices that result in improved soil and water conservation. Where such need has been generally recognized, producers in some instances have banded together in formal organizations for collective action to combat conservation problems. These organizations may, for example, adopt regulations which place the responsibility on the landowner for damage done to a neighbour’s property by sediments originating on his land. Application of prescribed preventive measures protects the owner from such liability. Community action has in many areas stimulated the application of control measures that appreciably reduce erosion. Such action to preserve and improve land and water resources is highly essential to avoid further degradation of these resources (FAO 1978a).

3.1.7 Government Policies

Similar to social influences, government policies (including laws, regulations, etc.) have an effect on crop production systems. These policies may result in land degradation on the one hand and resource conservation on the other.

Land degradation may result when local, state, regional, or national governmental policies encourage crop production on erosion-susceptible lands that are not adequately protected by use of suitable tillage systems or other conservation measures. Such production may be for domestic consumption or export, and may be encouraged through decrees, proclamations, laws and payment of subsidies. Land degradation may also result from policies which encourage or fail to prevent overgrazing and crop residue removal or burning (Fig. 42), which permit the use of tillage and related practices that are not conducive to resource conservation, and which result in the introduction of poorly planned programmes (FAO 1977a).

Fig. 42 Burning crop residues releases plant nutrients and minimizes tillage problems, but destroys residues that effectively conserve soil and water

When the need for resource conservation is recognized and a sufficient number of people are aware of it and desire that improved practices be adopted, then economically sound practices should be selected and developed, and policies and implementation plans can be formulated to achieve this goal. For successful implementation, a prime requisite is the creation of an awareness that a change is necessary on the part of the producer. Policy makers must also be made aware of this need (Fosbrooke 1974). Then, for successful and efficient implementation of the plans, all agencies concerned must work together as a team (Carpenter 1980; FAO 1977a). To ensure adoption, education of and technical assistance to the producer are usually necessary. Also, assistance in the form of food or cash may be necessary so that adoption of the practices does not result in an undue financial burden on the producer (Carpenter 1980; FAO 1977a, 1978a, b; Fosbrooke 1974). Adoption of improved practices is a benefit to the entire country, not just to the producer on whose land the practice may be applied.

3.2 CULTIVATION SYSTEMS

Since man forsook the nomadic way of life and began to till the soil to improve crop yields, many different types of cultivation systems have been developed. Also, many different types of tillage methods have been or are being used. A detailed discussion of all systems and methods is beyond the scope of this report. Therefore, the cultivation systems have been grouped into four generalized systems, namely, traditional shifting, labour intensive continuous, animal-draught and small tractor, and modern high-technology. These cultivation systems, along with some of the more important subsystems, are discussed in subsequent sections. The effects of tillage systems and methods and the use of supporting practices for conservation of soil and water resources are also discussed.

3.2.1 Traditional Shifting Cultivation

Shifting cultivation* is widely practised in Africa, South and Central America, Oceania and .Southeast Asia by people of widely varying origins and cultures. Estimates of land areas used for shifting cultivation range from 3.6 billion hectares (Hauck 1974) to 7 or 8 billion hectares (Lal 1979). It is estimated that at least 8 percent of the world's people obtain most of their food from lands under shifting cultivation. The practice is used on a variety of soils with many different types of vegetation, crops grown, length of cropping and fallow periods, and methods of tillage (Hauck 1974).

i. Advantages of shifting cultivation

The major advantages of shifting cultivation systems are the low capital inputs required, dependence on natural or regenerated soil fertility, and the opportunity to grow a variety of crops. Shifting cultivation achieves crop production with low capital inputs because the farmer or the family provides most or all of the labour, the implements for land clearing or tillage are simple, fire is a major factor in weed control, and fertilizers, etc. are not applied.

Labour expended per unit area for crop production varies widely and depends on such factors as native vegetation (forest or grassland), type of forest, tree density, intensity of land clearing, and secondary operations (tillage, weed control, etc.) (Dabasi-Schweng 1974; Ruthenberg 1974). As labour is by the farmer or the family, there is usually no capital outlay. Also, expenses for implements are minor because they are basically the axe for land clearing, the the hoe, cutlass or machette for tillage and weed control (Mouttapa 1974; Ofori 1974; Ruthenberg 1974).

On forested lands and on grasslands, fire provides some benefits with respect to weed control, thus minimizing capital inputs for that purpose. Heat from the fire destroys weed seeds and, to some extent, tree stumps and other plants not removed in the clearing operation. Crops planted in the burned areas grow quite well because of reduced competition from weeds or tree regrowth (Fosbrooke 1974; Moody 1974).

The dependence of shifting cultivation on natural or regenerated soil fertility is well known. Although cost to benefit ratios for applying fertilizers were highly favourable for various crops at several locations (Sanchez 1977; Zschernitz 1974), the practice has not been widely accepted. With increasing population pressures and resultant shorter fallow periods for soil fertility regeneration, greater use of applied fertilizers will undoubtedly be a key factor in stabilizing crop production, maintaining soil productivity and producing adequate food supplies.

ii. Disadvantages of shifting cultivation

The often mentioned advantages of shifting cultivation, that were discussed in the previous section, are also disadvantages in many cases. Failure to expend capital for fertilizers and herbicides, for example, results in declining soil fertility, greater weed problems, and the resultant need for high labour inputs to shift to a new plot. Also, burning forest litter, grasses and crop residues, which aids weed control, increases the potential for greater soil erosion. Other disadvantages of the system are the need to relocate the dwelling, large land area requirement and limited opportunity for mechanization.

Although capital inputs for fertilizers, herbicides, etc. could reduce the rate of decrease in soil fertility and minimize weed problems, capital is rarely available where shifting cultivation is practised. The basic goal of the shifting cultivator, often a subsistence farmer, is to provide a stable supply of food for the family. Only after this goal is met are cash crops considered. However, even then, growing additional crops for sale may be of little importance because of limited markets, poor roads and lack of satisfactory transportation.

Without applying fertilizers, soil fertility rapidly declines, usually resulting in the need to shift to a new plot in 2 to 5 years. Another factor contributing to the decision to shift is the aggressive regrowth of native vegetation. It may be more economical to clear a new site than to control weeds on the existing one (Ofori 1974), especially where capital is limited.

For maximum crop yields, all competition from weeds must be eliminated. If this is not possible, weed control in early growth stages of the crop is essential. Weeds can usually be controlled quite easily in the first season after land clearing, primarily because of the heat associated with burning to clear the land. Thereafter, weed control becomes more difficult, often requiring up to 50 percent of the farmer’s working time. When weeds can no longer be adequately controlled, yields decline and eventually the farmer is forced to abandon the plot (Moody 1974). Effects of weed competition on crop yield losses and benefits from herbicide use are given in Tables 5, 6 and 7.

Table 5 CROP YIELD LOSSES AS A RESULT OF NOT WEEDING CERTAIN CROPS (From Moody 1974)

Crop	Year 1970 %	1971 %	1972 %
Maize	19	19	28
Cowpea	51	48	59
Soybean	-	-	60
Yam	-	-	73
Sweet potato	-	-	91
Cassava	-	-	92
Upland rice	100	100	100

Table 6 EFFECT OF WEED COMPETITION ON THE YIELD OF CROPS IN COLOMBIA
(from Moody 1974)

Crop	Average loss %	Average increase in yield over local farmer practice from herbicide treatments %
Potato	17	20
Barley	19	16
Wheat	29	17
Cotton	31	13
Maize	46	21
Bean	51	24
Rice	54	24

Table 7 EFFECT OF PIGWEED (*AMARANTHUS* SPP.) ON SORGHUM GRAIN YIELD ON PULLMAN CLAY LOAM IN TEXAS (USA), 1966
(from Shipley and Wiese 1969)

Weed spacing in row cm	Weed dry matter yield kg/ha	Sorghum grain yield kg/ha	Sorghum yield reduction[1] %
No weeds	0	5 470	0
240	2 870	4 580	16
120	4 250	3 980	27
60	7 160	3 390	38
30	8 610	2 870	48
15	12 300	2 110	61
7.5	13 300	1 390	75

[1] Reduction in weedy area relative to area with no weeds.

The amount of labour expended for crop production on a unit of land devoted to shifting cultivation varies widely and depends on such factors as native vegetation, climate and crops being grown (Dabasi-Schweng 1974; Ruthenberg 1974). Rice production on virgin jungle land in Sarawak, for example, required from 135 to 171 man-days per hectare (56 to 71 per acre) whereas on secondary jungle land, it required 121 to 159 man-days per hectare. Major labour usage was for felling trees, weeding and reaping on virgin jungle land and for weeding and reaping on secondary jungle land. Relatively low amounts of labour were used for slashing, secondary clearing, dibbling, sowing and transport (Dabasi-Schweng 1974). Labour inputs on savanna and grasslands are generally low for initial slashing and felling, and high for subsequent burning, clearing and hoe cultivation (Ruthenberg 1974). Apparently, low intensity fires on grasslands and savannas do not provide as much weed control benefit as more intense fires on forest lands.

Labour for yam, maize and cotton production in the Ivory Coast was 150, 90 and 1350 man-days per hectare, respectively (Dabasi-Schweng 1974). However, for these and other crops on other lands, it would be affected by native vegetation and climate.

The influence of climate on labour usage is manifested largely through its influence on type of vegetation that grows in a given area and the aggressiveness with which that vegetation competes with crops. For good crop yields, that vegetation must be controlled, which in most cases involves labour. In dry climates, crop and weed growth may be poor, thus resulting in low labour inputs for crop production. In humid, tropical climates, some weed growth occurs throughout the year, which results in high labour inputs for weed control.

In a system of shifting cultivation, the high potential for soil erosion, which is more fully discussed in other sections, results primarily from low vegetative cover during the period from land clearing to crop canopy development (Moody 1974). The more thoroughly the land is cleared, the greater the potential for erosion. Burning of forest litter, crop residues and grasses is especially conducive to high erosion because it results in a bare soil surface before crops develop sufficiently to provide some protection. However, erosion may also occur after plant canopy development, especially if poor crop management practices are used. Erosion control in cropped areas improves as native vegetation or weeds provide additional soil cover, but competition from these plants may lower crop yields (Moody 1974). A mulch* of dead vegetation spread between plants minimized weed growth and also reduced erosion. Similar benefits could be derived by using herbicides to control weeds, thus providing an in-place mulch. Other means of controlling erosion are discussed in other sections.

A disadvantage peculiar to shifting cultivation is the need to move the dwelling. The type of dwelling, distance to be shifted, and crops grown will determine whether it is more advantageous to move the dwelling or to bring the products to the dwelling. Simple huts and associated structures can be readily moved (Fig. 43) whereas bringing crop products to the hut would entail considerable labour.

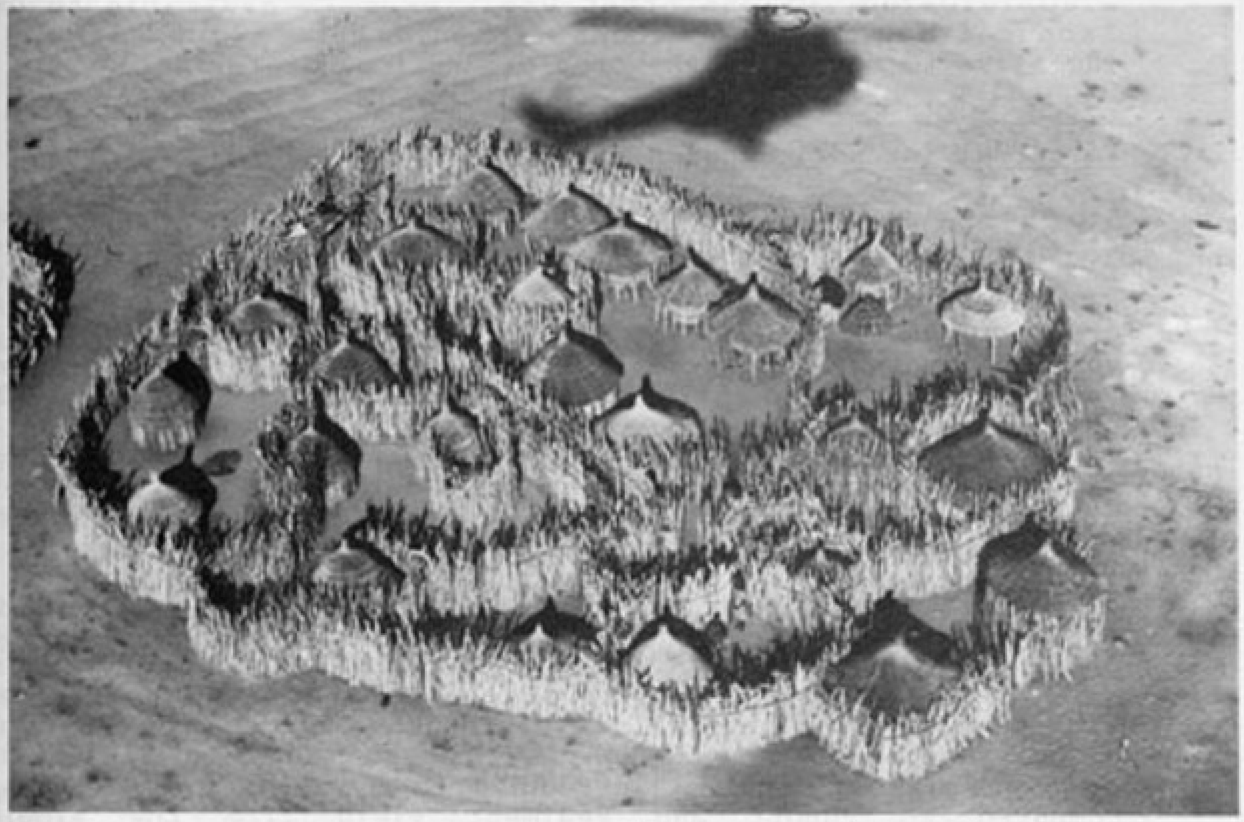


Fig. 43 Homes of the Ovambos in Namibia. Such huts can be moved with relatively little difficulty where shifting cultivation is practised (photo by James Brandenburg, copyrighted by National Geographic Society, June 1982)

To minimize the frequency of moving the dwelling, shifting to adjacent lands would be beneficial if suitable new land adjoined the presently used land. By shifting to adjacent lands, the dwelling may need to be moved only once for each two to four or six shifts to new fields if the dwelling is strategically located. Strategically locating dwellings becomes increasingly important as the quality of dwellings improves. Whereas simple huts can probably be moved or constructed with one man-day of labour (Dabasi-Schweng 1974), constructing higher quality dwellings may require considerably more labour.

A major disadvantage of shifting cultivation is the large land requirement. To restore fertility adequately, land must usually be fallowed from 5 to 10 years for each year that it is cropped. Such use of land is possible where population is sparse, but becomes increasingly difficult as population pressures increase. With more intensive cropping, yields decrease and land degradation increases unless improved crop production practices are introduced and adopted. This problem is further discussed in item vi. of this Section.

The lack of mechanization in shifting agriculture results from such factors as unavailability of equipment, limited capital and the deliberate choice of the farmer. For satisfactory use of machines in forested land, tree stumps must be removed, which requires special equipment or large labour inputs; neither may be available, nor capital to pay for the extra land clearing expenses. Capital may also not be available for purchasing farm machinery, and is a major factor where machinery is not used with shifting cultivation on savannas or grasslands. In these cases, however, producer choice is also involved. Unless other employment is available to use the labour freed by farm mechanization, there may be little or no incentive to mechanize the crop production enterprise.

iii. Potential for soil erosion

Severe soil degradation, because of erosion by water, has been attributed to shifting cultivation (Das 1980; Datiri 1974; Juo and Lal 1977; Lal 1974, 1979; Osuji *et al*. 1980; Voelkner 1979). Certainly, the magnitude of actual or potential water erosion is greater when sloping or slowly permeable soils are cleared of native vegetation or are clean-tilled, than when such soils have a complete vegetative cover (Gillespie 1981; Harrold and Edwards 1972; Lal 1974; Osuji *et al*, 1980; Stewart *et al*, 1975; Williams and Joseph 1970; Wischmeier and Smith 1978). The amount of erosion depends on tillage method, type of soil cover remaining, and soil slope. Some examples of actual or potential erosion by these factors are illustrated in Tables 8, 9, 10, 11 and 12.

Data in Table 8 (Harrold and Edwards 1972) were obtained from a storm in Ohio (USA) having an expected recurrence frequency of over 100 years. More than 12.7 cm of rain fell in 7 hours. Maize was grown on all watersheds. Rainfall was the same and slopes were similar for the clean-tilled watersheds with sloping (up and down slope) or contour rows. However, runoff was only 52 percent and sediment yield was only 14 percent from the contour-row watershed as compared to runoff and sediment yield from the sloping-row watershed. For the watershed planted to no-tillage* maize (planted in sod with contour rows), runoff was 57 percent and sediment yield was only 0.14 percent of that from the sloping-row watershed, even though the slope was much greater on the no-tillage watershed. These data illustrate the tremendous soil losses that can occur on unprotected sloping soils and the value of a vegetative cover for minimizing such losses. An illustration of soil losses on different slopes (Table 9) was given by Lal (1974).

Table 8 RUNOFF AND SEDIMENT YIELD FROM MAIZE WATERSHEDS AT COSHOCTON, OHIO (USA), DURING A SEVERE RAINSTORM (from Harrold and Edwards 1972)

Tillage	Slope %	Rainfall cm	Runoff cm	Sediment yield ton/ha
Ploughed, clean-tilled sloping rows	6.6	14.0	11.2	50.7
Ploughed, clean-tilled contour rows	5.8	14.0	5.8	7.2
No-tillage, contour rows	20.7	12.9	6.4	0.07

Table 9 SOIL LOSSES DUE TO EROSION BY WATER FROM UNPROTECTED PLOTS OF DIFFERENT SLOPE GRADIENTS (from Lal 1974)

Soil slope %	Soil loss tons/ha
1	3.5
5	37
10	49
15	115

The effect of various tillage practices on soil losses was measured by Osuji *et al*. (1980) at Ibadan in western Nigeria (Table 10). The tillage practices were:

a. Bare fallow*: the plots were ploughed twice and kept free of weeds or any vegetative cover. This treatment served as the control.

b. Plough only: the plots were ploughed twice with a mouldboard plough.

c. Plough and harrow (conventional): the plots were ploughed twice and then harrowed once.

d. No-tillage: the existing vegetation was killed with gramoxone[1] applied at the rate of 2.5 litres/ha. Planting was in strips, and grass mulch was applied at the rate of 4 tons/ha. No grass mulch was applied in the late season of 1978.

e. “Manual”: this treatment was an imitation of the typical local peasant practice. All cultural operations were done by hand and with local implements.

[1] Chemical names for herbicides are given in Appendix 3.

Table 10 EFFECT OF TILLAGE PRACTICES ON SOIL LOSS IN 1976 AND 1977 (from Osuji et al. 1980)

Year	Treatments	lst season	2nd season	Total
		.... tons/ha		
1976	No-tillage	0.04	0.01	0.05
	Manual	3.41	1.20	4.61
	Plough	5.01	2.75	7.76
	Conventional	5.27	3.19	8.46
	Bare fallow	10.22	7.41	17.63
	LSD (P = 0.05)	3.18	2.53	4.5
1977	No-tillage	0.06	0.02	0.08
	Manual	4.10	2.50	6.60
	Plough	5.90	2.95	8.85
	Conventional	6.20	3.50	9.80
	Bare fallow	11.56	7.96	19.52
	LSD (P = 0.05)	3.21	2.40	4.63

The results clearly show the value of surface residues, as maintained by no-tillage, for reducing erosion. The “manual” treatment, typical of the practice used by peasants in the area, resulted in relatively low, yet significant soil losses. This indicates that any disturbance of soil or the vegetative cover subjects the land to erosion unless a practice such as no-tillage is used.

Stewart et al. (1975) discussed the effect of crops, tillage systems, rotations, and other management practices on C, the cover and management factor, of the USLE (Wischmeier and Smith 1978). The C values range from 0.001 for well-managed woodland to 1.0 for continuous fallow land tilled up and down the slops. In general, C values decrease as increasing amounts of residue or vegetative cover are maintained on the soil surface for increasing amounts of time during the crop production cycle. The greatest protection was afforded by a grass and legume mix (C value of 0.004), which was almost as effective as that provided by well-managed woodland (C value of 0.001).

Although many factors affect soil erosion, as previously discussed, a highly important factor is soil detachment due to raindrop impact. This is illustrated by data in Table 11 (Williams and Joseph 1970).

Table 11 EFFECT OF SOIL COVER ON EROSION (from Williams and Joseph 1970)

Treatment	Total soil loss in 3 years tons/ha
Permanent grass sward (protection from raindrop impact and reduced runoff)	7.4
Two layers of mosquito gauze 15 cm above bare soil surface (minimizing drop impact, no reduction of runoff)	6.7
Bare soil	780

Losses from unprotected bare soil were about 100 times greater than with a permanent grass cover, which provided protection against raindrop impact and runoff. Results with the gauze treatment show that minimizing drop impact was the controlling factor because run-off was not impeded by the gauze above the surface. Although not given, runoff undoubtedly was less under the gauze than from bare soil because surface sealing due to soil dispersion should have been minimal under the gauze, thus providing for more rapid water infil-tration.

The soil disrupting action of a single drop of water is illustrated in Fig. 18. Figure 44 illustrates the protective action of vege-tation for intercepting raindrop impact and Figure 45 the magnitude of soil loss from an unprotected soil.

Fig. 44 Plants intercept raindrops, thus protecting the soil surface against erosion (USDA-Soil Conservation Service photo, issued by FAO)

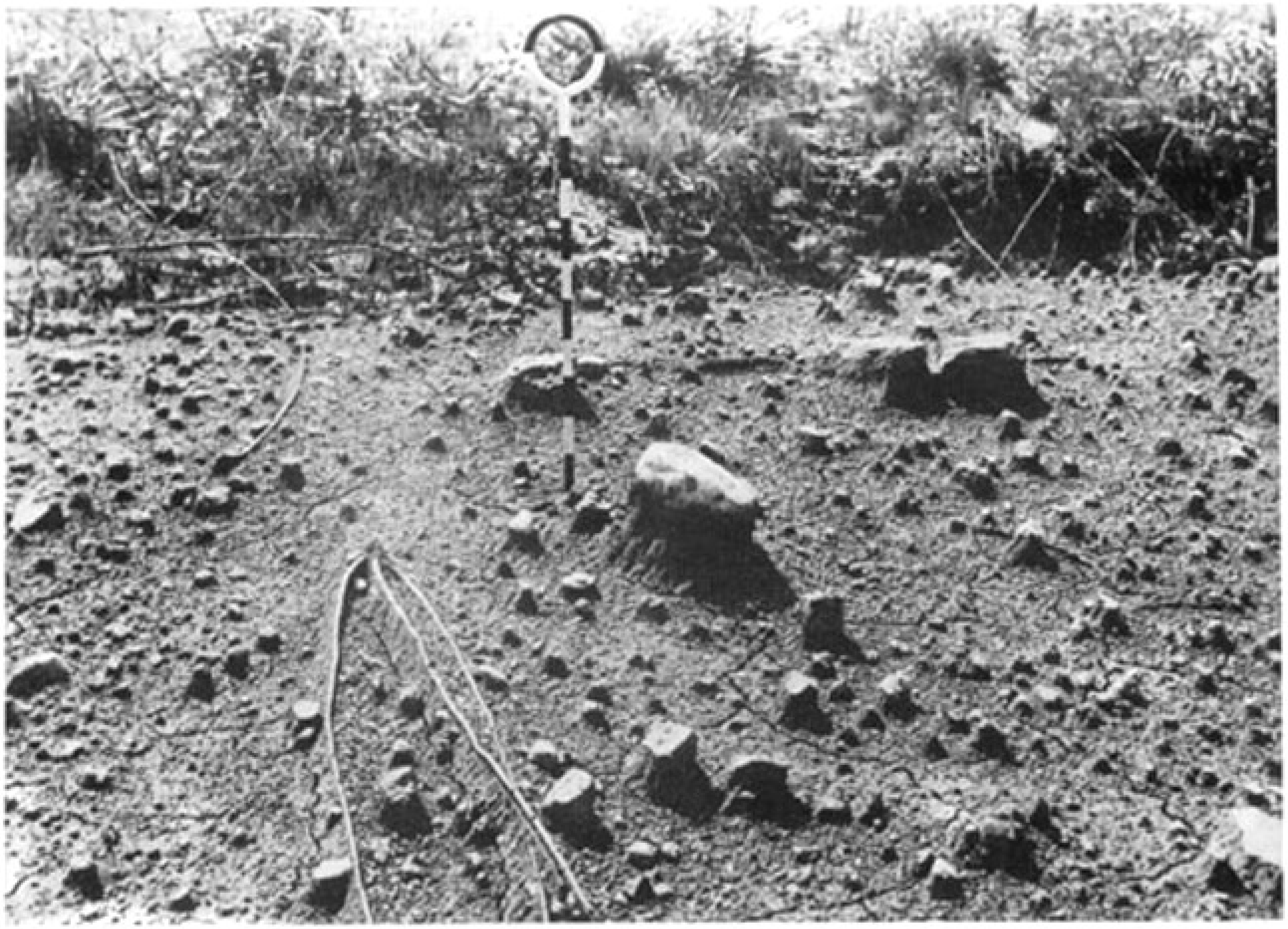


Fig. 45 Erosion removed soil from unprotected areas, leaving behind soil pedestals capped by rocks (USDA-Soil Conservation Service photo, issued by FAO)

iv. Potential for lon -term use of shifting cultivation

Although the data in Tables 8 to 11 illustrate the adverse effects of clean tillage with respect to soil erosion, they also illustrate that practices which retain some residues on the surface are generally quite effective for controlling erosion (Table 10). The "manual" tillage treatment tended to result in less erosion than the plough or conventional treatments. This suggests that, with good management, shifting cultivation per se probably does not lead to greater land degradation than other systems. For example, people in primitive tribes that followed the instructions of the elders with regard to land rotation and water use were able to maintain themselves in the same place for hundreds of years in a harsh environment by using the "digging stick" as their basic tool. Introduction of a tractor to such environment without disciplined land use would probably ruin the land, a national asset, in less time than it would require to wear out the tractor (Fosbrooke 1974).

With sufficiently long fallow periods and use of good management practices, land can be cropped for long periods without serious degradation in a shifting cultivation system (Fosbrooke 1974; Pierson 1974). Factors contributing to minimal land degradation due to soil erosion include the practice of interplanting crops, culture of rapidly growing crops, use of the hoe and cutlass or machette (Mouttapa 1974; Ofori 1974), maintenance of some residues on the surface (Mouttapa 1974; Seubert et al. 1977), and use of land clearing methods that result in quicker recovery of woodlands (Fosbrooke 1974).

Monoculture is not and never has been common in1 a system of shifting cultivation. By interplanting crops, soil is covered with vegetation most of the time and, therefore, quite adequately protected against erosion. In addition, interplanting ensures against crop failure and provides a steady supply of fond for the subsistence farmer. Additional protection against erosion occurs when a rapidly growing crop, such as the yam, is used in the intercropping system (Ofori 1974).

Common implements of the subsistence farmer engaged in shifting cultivation are the hoe and cutlass or machette. In forest regions, use of these implements disturbs the soil only slightly, especially where tree stumps are not removed and, therefore, does not result in serious erosion.

The land clearing method has a major influence on soil erosion in a system of shifting cultivation. Removal of all residues by burning or other methods leaves a soil highly susceptible to erosion, especially on shallow grassland soils (Ofori 1974) and on sloping forest soils (Fig. 9) (Lal 1979). However, the slash-and-burn clearing method resulted in less erosion than mechanical (bulldozer) clearing of a tropical forest in Peru (Seubert et al. 1977). Use of the bulldozer caused severe compaction and removed the root mat from soil, which greatly reduced water infiltration compared with that on burned plots (Fig. 46). Burned plots retained their root mat, and the soil surface was protected against raindrop impact by ashes and charred materials on the surface (Fig. 47).

According to Fosbrooke (1974), some people in Zambia use a system of forest clearing that results in rapid regeneration of the woodland and restoration of soil fertility during the fallow period. To achieve this, trees are cut at breast height, but the cut branches are not stacked around the remaining stumps; therefore, tree stumps are not killed when the branches are later burned. This results in trees becoming rapidly re-established when the land is returned to fallow. Such a system of land clearing undoubtedly results in greater competition between crops and tree regrowth or weeds, but helps to minimize erosion because more tree stumps and litter are maintained on the land than where it is more intensively cleared.

v. Factors responsible for land degradation in shifting cultivation

Apparently the basic cause of land degradation where shifting cultivation is practised is the increased pressure resulting from the rapidly expanding population on a generally limited land area, which results in the land being fallowed for shorter periods. With the shorter fallow, soil fertility is not adequately restored before the land is again cultivated. More frequent cultivation and poor management practices, coupled with use of naturally low-fertility land in some countries, does lead to land degradation with shifting cultivation and is of major concern (Fosbrooke 1974; Greenland 1974; Hauck 1974; Lal 1974, 1979; Mouttapa 1974; Ofori 1974; and many others).

The periods of cropping and fallow in shifting cultivation systems vary widely. Normally, regrowth (fallow) is allowed for 12 to 20 years to restore soil fertility after which the land is again cropped for 2 to 4 years. These periods are generally applicable where land is abundant and population pressures are low. As population pressures increase, land is usually cropped more frequently and often before soil fertility has been restored. Cropping under such conditions leads to a degenerative cycle of increasingly lower

Fig. 46 Equipment used for jungle clearing in the Gal Oya valley of Sri Lanka. Heavy equipment may cause severe soil compaction, thus low water infiltration (FAO photo)

Fig. 47 Shifting cultivation in Indonesia. Land cleared by felling trees and burning. Felled trees and charred vegetation afford some protection against erosion (FAO photo)

yields and lower fertility (Greenland 1974), and may be compounded by increased erosion because of reduced vegetative cover on the land (Lal 1974). The final result is a degraded system (Greenland 1974).

vi. Maintaining productivity with shifting cultivation

The basic scientific principles for maintaining or enhancing soil fertility are known, and are the same whether the land is cultivated in small plots or large fields and whether ploughs or hoes are used. The challenge is to introduce and gain acceptance of improved soil fertility and related soil and water conservation practices before the land becomes irreversibly degraded. To achieve this most effectively, the improved practices must be harmonized with existing agricultural systems (Greenland 1974). In addition, introduction of improved practices must be thoroughly planned and confirmed to be suitable (technically, socially and economically) to the average farmer (Braun 1974a), and must be coordinated through and have the full cooperation of all agencies concerned (Carpenter 1980).

Results from trials and demonstrations on farms under shifting cultivation in several countries have shown that added fertilizers or use of a good fallow crop in rotation, or a combination of the two, can lead to cropping for a longer time (thus permitting longer fallow periods) or even continuous cropping (Adetunji and Agboola 1974; Wild 1974; Zschernitz 1974). The above reports indicated that, although variable, responses to added N were similar to those in other parts of the world and responses to P were very much higher. Sanchez (1977) also reported a good crop response to N, and also to K, Ca, Mg, Zn, Cu, Mo and B, but not to P, on some highly deficient humid tropical soils in South America. The poor response to applied P was because P was fixed in the strongly acid soils.

Where good responses to fertilizers can be demonstrated, farmers are more likely to accept fertilizers because they realize that declining fertility necessitates a shift to a new plot. However, the economics of fertilizer use must also be advantageous (Wild 1974).

The adverse effect of declining soil fertility is generally recognized by farmers. When applied fertilizers maintain soil fertility and, therefore, permit cropping for a longer time, the advantages of applied fertilizers are similarly apparent. Such is often not the case with soil and water conservation measures because soil losses are sometimes virtually imperceptible and the benefits of conserved soil water are not readily understood, especially in the more humid regions. Therefore, implementation of improved soil and water conservation measures is, in general, more difficult than implementation of improved fertilizer practices.

The basic implements of the shifting cultivator, as previously mentioned, are the hoe and the cutlass or machette, especially on forested lands. Consequently, soil disturbance and subsequent soil erosion due to tillage method are usually slight unless the soil is kept bare by use of these implements or if the forest litter or grasses are burned before the cropping period (Lal 1974; Ofori 1974).

Because of the negligible soil disturbance with the basic implements, practices other than tillage must be introduced and used to minimize soil and water losses where shifting cultivation is practised. One practice that probably contributes more to soil erosion than any other factor is the burning of forest litter, grasses and crop residues. Therefore, by eliminating burning and using implements that minimally disturb the soil, the potential for erosion could be greatly reduced. However, to obtain satisfactory weed control, the use of herbicides may be necessary. Where weeds were controlled with herbicides in a no-tillage system, runoff and erosion were greatly reduced as compared to where tillage was used for weed control (Tables 8, 10, 12). Through use of the no-tillage system, a good cover of plant residues was maintained on the soil which intercepted and minimized the impact of raindrops, and which decreased the runoff velocity (Lal 1974).

Table 12 EFFECT OF TILLAGE ON RUNOFF AND SOIL LOSSES FROM LAND CROPPED TO MAIZE IN NIGERIA (from Rockwood and Lal 1974)

	Bare fallow		Ploughed		No-tillage	
Slope %	Runoff %	Soil loss ton/ha	Runoff %	Soil loss ton/ha	Runoff %	Soil loss ton/ha
1	18.8	0.2	8.3	0.04	1.2	0.0007
5	20.2	3.6	8.8	2.16	1.8	0.0007
10	17.5	12.5	9.2	0.39 [sic][2]	2.1	0.0047
15	21.5	16.0	13.3	3.92	2.2	0.0015

1 Rainfall was 44.2 mm.
2 Probably an error.

Surface residues form mulches in no-tillage systems, and mulches are widely recognized for their value in reducing runoff, erosion and soil water evaporation (Greb et al, 1967, 1970; Harrold and Edwards 1972; Jacks et al. 1955; Mannering and Meyer 1961, 1963; Meyer et al, 1970; Taylor et al. 1964; Unger 1978a; Unger and Wiese 1979; and others). The effects of surface residues (mulches) on runoff and erosion are illustrated in Tables 8, 10, 11 and 12. The value of a surface mulch for water conservation through enhanced infiltration and reduced evaporation is illustrated in Table 13. Yields of

Table 13 MULCH RATE EFFECTS ON SOIL WATER STORAGE DURING FALLOW AND SUBSEQUENT SORGHUM GRAIN YIELDS, BUSHLAND, TEXAS (USA) 1973-76 (from Unger 1978a)

Mulch rate metric tons/ha	Precipitation storage cm	Yield kg/ha
0	7.2 c[2]	1 780 c[2]
1	9.9 b	2 410 b
2	10.0 b	2 600 b
4	11.6 b	2 980 b
8	13.9 a	3 680 a
12	14.7 a	3 990 a

1 Average precipitation during fallow was 31.8 cm.

2 In each column, values followed by the same letter are not significantly different at the 5% level according to the Duncan Multiple Range Test.

sorghum for grain planted after fallow were increased by additional water stored in the soil due to the application of wheat straw mulch (Unger 1978a). Similar benefits from applied mulches were obtained in some semi-arid tropical regions (Prihar et al. 1975, 1979). Besides resulting in improved water conservation and thereby supplying additional water to crops, mulches also result in higher water contents at or near the soil surface (Unger 1978a; Unger et al. 1971), thus improving conditions for seed germination and seedling establishment (Unger 1978a, 1982a). A disadvantage of using mulches is the difficulty in planting through a mulch. For satisfactory planting, a special planter may be needed, or the mulch may need to be removed and then replaced after planting (Unger 1982a). Mulches, however, may cause no major problems where simple implements like the hoe or dibble stick are used for planting, as in shifting cultivation systems.

Adequate mulching materials may not be available in many instances because of low residue production, its use as animal feed or as fuel, and its rapid deterioration due to weathering or termite activity (Barber et al. 1980). To obtain sufficient mulching materials, some land may need to be devoted to residue-producing crops, which may not be practical because of limited land areas or the extra effort needed to grow, cut and transport the crop to be used as a mulch (Moody 1974). Where residue amounts are limited, benefits from them with respect to soil and water conservation are still possible through the use of reduced or minimum tillage systems that maintain most residues on the soil surface (Lal 1974; Moody 1974).

Besides tillage, practices that have potential for conserving soil and water resources in shifting cultivation systems include use of strip cropping, mixed cropping, cover crops, contour ridging, basin listing (furrow dykes or dams, tied ridging), crop rotations, and phased plantings (Datiri 1974; Lal 1974; Ruthenberg 1974). These practices are discussed in greater detail in subsequent sections.

3.2.2 Labour Intensive Continuous Cultivation

As compared to shifting cultivation for which land is fallowed for a longer period than it is cropped, continuous cultivation refers to annual cropping. However, fallow periods of 1 or 2 years may be used occasionally.

In this section, labour intensive systems of continuous cultivation are discussed under the subheadings of subsistence and extra production continuous cultivation.

The first case is a continuous cropping system at subsistence level that replaces shifting cultivation when available land resources have been completely utilized due to steadily increasing population pressures (with shifting cultivation, unproductive land was fallowed until fertility was restored, then recropped). Unless improved practices have been introduced and adopted, crop production under these subsistence conditions may result in serious or irreversible land degradation.

Favourable crop yields are possible with the second type of continuous cultivation, which involves the use of suitable practices to avoid soil fertility decreases and to guard against other forms of land degradation. Crop production under such conditions involves a knowledge of and commitment to use of sound resource conservation practices. To maintain or improve soil fertility, naturally occurring plant nutrients are usually recycled, but some fertilizers may be applied. Other suitable practices can be used to provide protection against erosion.

i. Subsistence continuous cultivation

Labour intensive continuous cultivation at the subsistence level is similar to traditional shifting cultivation in most regards, except that a plot of land is cropped for a longer period than it is fallowed (Greenland 1974; Okigbo 1980). As for shifting cultivation, the basic tools are the hoe and cutlass or machette, which disturb soil only slightly. Because a plot is cropped continuously major clearing is not necessary each season. However, greater effort is usually required to control weeds because weed problems generally increase as the period of cultivation increases (Dabasi-Schweng 1974; Moody 1974; Ruthenberg 1974).

Under poorly managed conditions with no provisins for soil fertility maintenance and soil and water conservation, crop yields decrease and land degradation intensifies (Greenland 1974). With improved management, such as soil fertility maintenance through recycling of various organic wastes (manure, household refuse, crop residues, etc.), the growing of soil-improving crops in rotation, and the use of other resource-conserving practices, good crop yields can be obtained without serious land degradation (Okigbo 1980).

Practices to maintain soil productivity and to improve soil and water conservation under continuous cultivation at the subsistence level are basically the same as those discussed for shifting agriculture (Section 3.2.l.vi). The use of mulches, however, may be more important with continuous cropping. Mulches not only reduce runoff, soil losses and evaporation, but also aid in weed control (Lal 1980). The latter is of major importance for the reason mentioned above. Also, mulches improve water conservation, which may improve crop yields with continuous cropping, especially in limited rainfall regions (Lal 1980; Mutea et al. 1980; Unger 1978a; Unger and Wiese 1979).

Residue burning in continuous cropping systems often leads to increased runoff and erosion, decreased water conservation, and decreased soil fertility (Balasubramanian and Nnadi 1980; Ofori 1974, 1980; Poulain 1980). The effect of burning on crop yields, however, is variable with yield decreases (Ofori 1980), little or no effect on yields (Balasubramanian and Nnadi 1980; Unger e 1973), and yield increases (Lyonga 1980) having been reported for some relatively short-term studies. Residue burning in the long run usually decreases yields (Bennett et al. 1954; Massee et al. 1966), apparently through its effect on nutrient and water supply, soil erosion and soil physical conditions (Balasubramanian and Nnadi 1980; Barnes and Bohmont 1958; Bennett et al. 1954; Lal 1980; Luebs 1962; Lyonga 1980; Massee et al. 1966; Poulain 1980).

ii. Extra production continuous cultivation

This labour intensive continuous cultivation system is also based mainly on hand labour for the necessary cultural operations. The basic tools are spades and hoes, but some other implements are used.

In contrast to farmers under subsistence conditions, whose main interest is in a stable supply of food for the family, farmers under extra production conditions normally produce more than required by the family. Both usually grow a variety of crops for family use (Braun 1974b; Harwood and Price 1976; Okigbo and Grceenland l976), but the latter type also grow one or more crops for commcercial use, and animal production may be involved in association with crop production (Okigbo 1980).

To achieve continuous crop production at above the subsistence level, farmers in this system maintain soil fertility at adequate levels and employ other practices that permit such intensive use without serious land degradation. The need for such intensive cropping results primarily from large numbers of people on limited areas of arable land. In essence, this intensive cultivation is a favourable solution to land degradation problems where increased population pressures result in drastically shortened fallow periods with shifting cultivation.

Through use of intensive cropping systems, farmers in some countries have provided a relatively abundant supply of food, even though the number of people per unit of arable land is high (FAO 1977c, 1978b). Based on arable land areas and estimated populations (Harwood and Price 1976; World Atlas 1978), each hectare of arable land supports about 19 people in Japan, 17 in Taiwan (in China) and 14 in Korea. Other high population-density countries are China (People's Republic) and Indonesia (each 7/ha) and Bangladesh, Nepal, Sri Lanka and Viet Nam (each 6/ha) (Harwood and Price 1976). With population densities like these, it is imperative that intensive crop production practices be employed to meet the people's food requirements. Although some farm machines are used in these countries, most people, especially in China (People's Republic), live in rural areas (FAO 1977c), derive their livelihood from farms, and provide the necessary labour for crop production.

Advantages of extra production continuous cultivation are: realization that soil and water resources must be conserved, improved soil fertility maintenance, recycling of organic wastes, improved soil conservation and improved soil physical conditions. Disadvantages are: high labour requirements, limited arable land for expansion, owner's land in several tracts (fragmentation), unfavourable terrain, limited organic wastes to manage, and costly or limited fertilizers. They are discussed in greater detail in the following paragraphs.

a. Advantages

A major advantage of extra production labour intensive continuous cropping systems is the producers' realization, in some cases, that soil and water resources must be conserved to obtain satisfactory crop yields to meet the food requirements for the people of the country. Closely associated with this realization is the producers' commitment to develop or adopt satisfactory crop production practices that conserve these resources. If this commitment is made and if it has widespread support throughout the population, then secondary advantages are soil fertility maintenance, favourable crop yields and good erosion control. A final advantage, not necessarily related to the above, is the potential for tilling a high percentage of the arable land. Little land is devoted to roads, and turning areas for equipment are generally narrow and, furthermore, they are not needed where hand labour is used exclusively.

Soil fertility in labour intensive cropping systems is maintained largely through intense recycling of waste materials derived from the land. These materials include animal wastes (manure and urine), human wastes (faeces, urine, garbage, etc.), crop wastes (straw, stalks, leaves, grasses, weeds, etc.), green manure and aquatic plants, nutrient-laden silt, and other sources (FAO 1977c). In China, it is estimated that recycling of organic wastes provides about two-thirds of the total nutrient requirement for crops (FAO 1977c; 5ingh and Balasubramanian 1980), nutrients that are often lost in modern high technology systems. Other favourable responses to intensive recycling of waste products were reported by Agboola (1980), Ofori (1980) and Poulain (1980). Recycling of organic wastes returned most nutrients that were removed by crops. It also maintained soil organic matter contents at relatively high levels, which made it much easier to sustain high levels of productivity as compared with that on low organic matter soils (Greenland 1980). Not only are major plant nutrients provided by recycling organic wastes but, on most soils, there are no micro-nutrient deficiencies where organic wastes have been used for a long time (FAO 1977c).

Recycling of organic wastes is labour intensive and requires such activities as collecting, mixing, composting and spreading the wastes. Different types of wastes require different activities. Household or urban refuse must be collected and spread on land (possibly after composting and mixing). Crop residues can be grazed by livestock with manure retained on the land, collected and fed to livestock with manure returned to the land, or retained on land with nutrients released by burning, decay on the surface, or by mixing with soil.

Residue burning returns such nutrients as P, K, Ca and Mg to soil, but results in major losses of N and S (Poulain 1980). Improved conservation and return of N and S can be achieved by allowing residues to decay in place (on the surface or in the soil) (Balasubramanian and Nnadi 1980; Poulain 1980).

Mixing residues with soil by use of hand implements is difficult and labour intensive. Therefore, the development of no-tillage systems for arable crop production was a major advance for efficient recycling of organic wastes, especially for crop residues (Greenland 1980). Through use of these systems, residues are maintained in place and weeds are mainly controlled with herbicides. As the residues and weeds decay, nutrients are released and returned to the soil, which improves soil fertility and crop yields. Besides the effect on soil fertility and crop yields, recycling of organic wastes is also beneficial with respect to soil and water conservation, especially where no-tillage cropping systems are used.

The benefits of no-tillage systems for reducing runoff and soil losses have been discussed previously and illustrated in Tables 8, 10 and 14. Surface residues are also beneficial for wind erosion control (FAO 1978a), and result in higher organic matter contents in the upper soil layer than where residues are removed (Agboola 1980; Balasubramanian and Nnadi 1980; Mutea *et al*. 1980) or mechanically mixed with soil (Agboola 1980; Lal 1980; Unger 1968, 1982b). Soil organic matter contents decrease with time and intensity of tillage (Agboola 1980; Haas *et al*, 1957; Hobbs and Brown 1957, 1965; Johnson 1950; Oveson 1966; Unger 1968, 1982b; van Bavel and Schaller 1951; White *et al*, 1945) and eventually reach new equilibrium levels compatible with prevailing environmental conditions (climate, crops grown, tillage, etc.) (Haas *et al*. 1957; Hobbs and Brown 1957, 1965; Unger 1982b).

There are many benefits from maintaining soil organic matter contents at relatively high levels. With respect to soil and water conservation, the benefits are related mainly to soil physical conditions. Increased organic matter contents result in improved soil aggregation and structure (higher porosity and lower bulk density), higher water infiltration, higher water-holding capacity, and lower soil erosion (Agboola 1980; Allison 1973; Gaikwad and Khuspe 1976; Jamison 1953; Lal 1974, 1980; Lyonga 1980; Peele *et al*. 1948; Poulain 1980; Unger 1975a), all of which generally result in improved crop production.

Organic matter content strongly influences soil aggregation and, therefore, a soil's susceptibility to erosion, both by wind or water. As a rule, aggregate stability increases with increases in organic matter content. However, soil from high organic matter (no-tillage) plots in Texas (USA) had more small (<1.0 mm) and fewer large (>4.0 mm) diameter water-stable aggregates and more small (<0.84 mm) and fewer large (>6.4 mm) dry aggregates than soil from plots (sweep or disk tillage) with less organic matter (Unger 1982b; Unger *et al*. 1980).

The size trends in both water-stable and dry aggregation suggested that soil from no-tillage plots would be more erodible by water and wind, respectively, than soil from sweep or disk tillage plots. For dry aggregates, the large amount of aggregates <0.84 mm diameter could lead to greater wind erosion. However, the soil (clay loam Pullman[1]) was adequately protected from erosion by surface residues (Unger *et al*. 1980).

Small water-stable aggregates are more readily moved by water than larger aggregates (Sood and Chaudhary 1980). However, small aggregates when water stable should resist dispersion as well or better than large aggregates and, therefore, result in maintaining relatively high water infiltration rates. Besides, the added protection provided by surface residues minimizes the potential for water erosion (Sood and Chaudhary 1980; Unger *et al*. 1980).

The importance of soil organic matter with respect to water infiltration is mainly related to its stabilizing effect on soil aggregates and improvement of soil structure. Stable aggregates resist dispersion and, consequently, minimize surface sealing due to raindrop impact or application of irrigation water. Unsealed surfaces permit greater infiltration of water than sealed surfaces.

Infiltration is also affected by the structure of soil beneath the surface. A stable, well-developed, granular structure permits greater water infiltration than a dense, poor-structured soil. Soil structural improvements results from such factors as root activity, freezing and thawing, wetting and drying, and activities by micro-organisms, fungi, animals, etc.

Earthworms are especially beneficial for forming channels in soils (Gantzer and Blake 1978; Hopp and Slater 1961). When earthworm or root channels and other soil pores extend to an unsealed soil surface, the potential for water infiltration is much higher than when these pores or channels are destroyed by tillage (Dixon 1978; Gantzer and Blake 1978; Hopp and Slater 1961).

Intensive soil tillage and earthworm activity are highly incompatible, whereas the no-tillage system favours earthworm activity (Gantzer and Blake 1978), provided the soil contains adequate organic matter. The no-tillage farming system is not adapted to compacted or degraded soils. On such soils, cover crops should be grown to restore soil fertility, improve soil structure and increase soil organic matter content in preparation for no-tillage farming (Charreau 1977; Lal 1980).

[1] Classification of soils is given in Appendix 4.

Fig. 48 Small fields of Sherpa villagers in Nepal (photo by Nicholas DeVore III, copyrighted by National Geographic Society, June 1982)

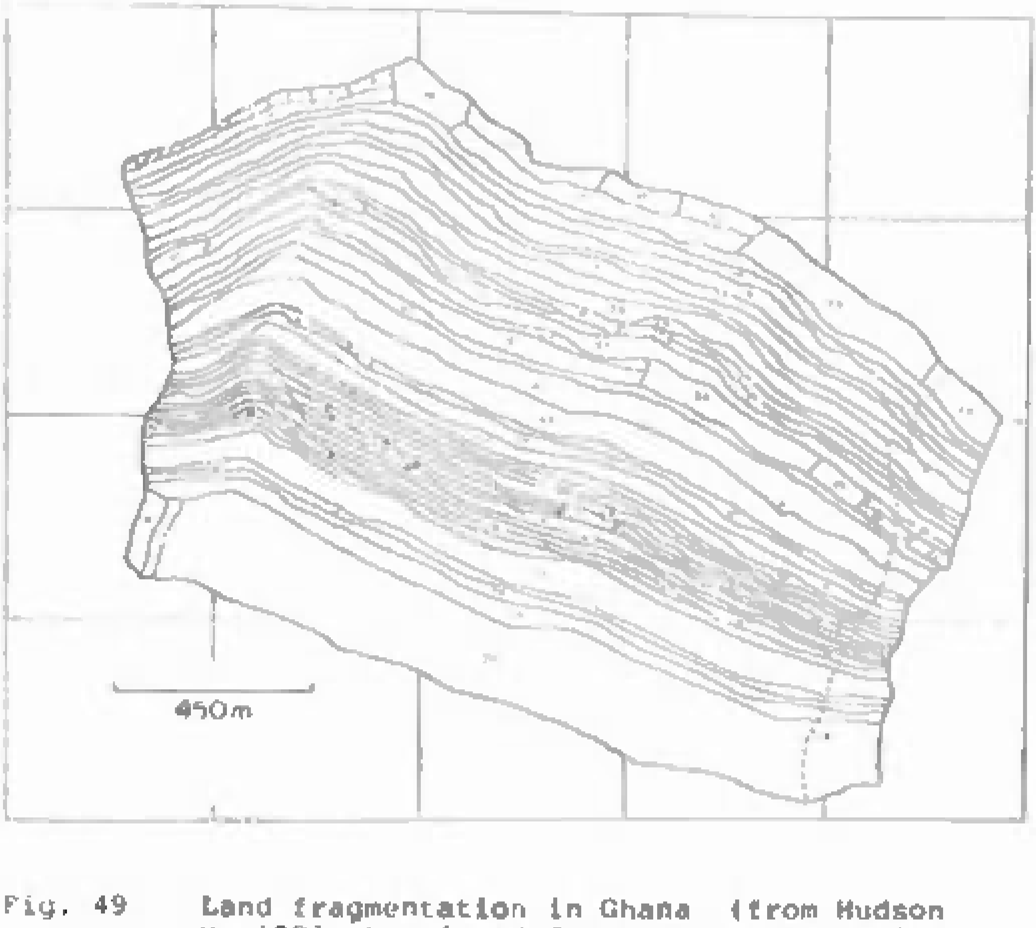


Fig. 49 Land fragmentation in Ghana (from Hudson N. 1981. Reprinted from Soil Conservation 2nd Ed., with permission from Cornell Univ. Press, Ithaca, and B.T. Batsford, London, to use copyrighted material)

b. Disadvantages

As for shifting cultivation and subsistence continuous cultivation, the labour requirement is high for extra production labour intensive continuous cultivation. The labour is provided mainly by the farmer and his family, but some hired labour may also be used.

The high labour requirement is not a serious disadvantage in countries with a numerous rural population (Southeast Asia, most of Africa, and much of South America) because labour is usually plentiful and work on farms provides employment. As labour is diverted to other uses, less is available for crop production, which then results in higher labour costs or inadequate labour to perform the necessary cultural operations.

Where costs are high or labour inadequate, resource conservation and crop production may be adversely affected unless suitable substitutes for labour are available. These include mulching to reduce weed competition, use of herbicides to control weeds (no-tillage), and grazing of cropland by animals for direct return of nutrients to the soil. These practices have been previously discussed. Another method of overcoming labour shortages is to use draught animals or tractors, with suitable implements, to perform at least some of the cultural operations. Crop production involving animals or small tractors is discussed in more detail in Section 3.2.3.

Much of the land intensively cultivated by hand labour is not suitable for widespread use of animal or tractor drawn implements because of small sizes of plots and the terrain on which they are located. Small plot sizes result from limited land areas suitable for cultivation (high population pressures), inability to farm larger areas (limited resources), and partitioning of land among heirs.

With plentiful land and shifting cultivation (no direct ownership), a farmer could cultivate as much land as was needed to supply food for the family or as much as could be cultivated with resources available to him (usually his labour and that of family members). With increasing populations, a land-availability restriction as well as the limited-resources (labour, etc.) restriction result in relatively small areas being cultivated by a particular farmer. As a general rule, a family unit can handle only about 1.5 to 2.0 hectares of land, unless some improved practices (for example, no-tillage) or mechanization are used (personal communication, T.F. Weaving, FAO, Rome). On such areas, it may not be an advantage to divert limited resources to the acquisition of improved farming equipment because it may not be efficiently utilized.

A factor resulting in small areas being cultivated is the repeated partitioning of land among heirs. Because each heir is entitled to a plot of equal size and productivity, such land partitioning often results in small or odd-shaped areas that are difficult to cultivate efficiently (FAO 1970; Hudson N. 1981). Examples of land partitioning in Nepal, Ghana and Uganda are shown in Figures 48, 49 and 50, respectively. Under such conditions, soil and water conservation measures are restricted to manual ones (mulching, no-tillage, possibly contouring) because the plots are too small for tractors and may even be too small for animal-drawn implements.

Another factor restricting crop production to hand labour in many situations is the terrain on which crops are produced. An extreme example is the use of bench terraces on steeply sloping land. In some instances, the terraces are only about one metre wide (Hudson

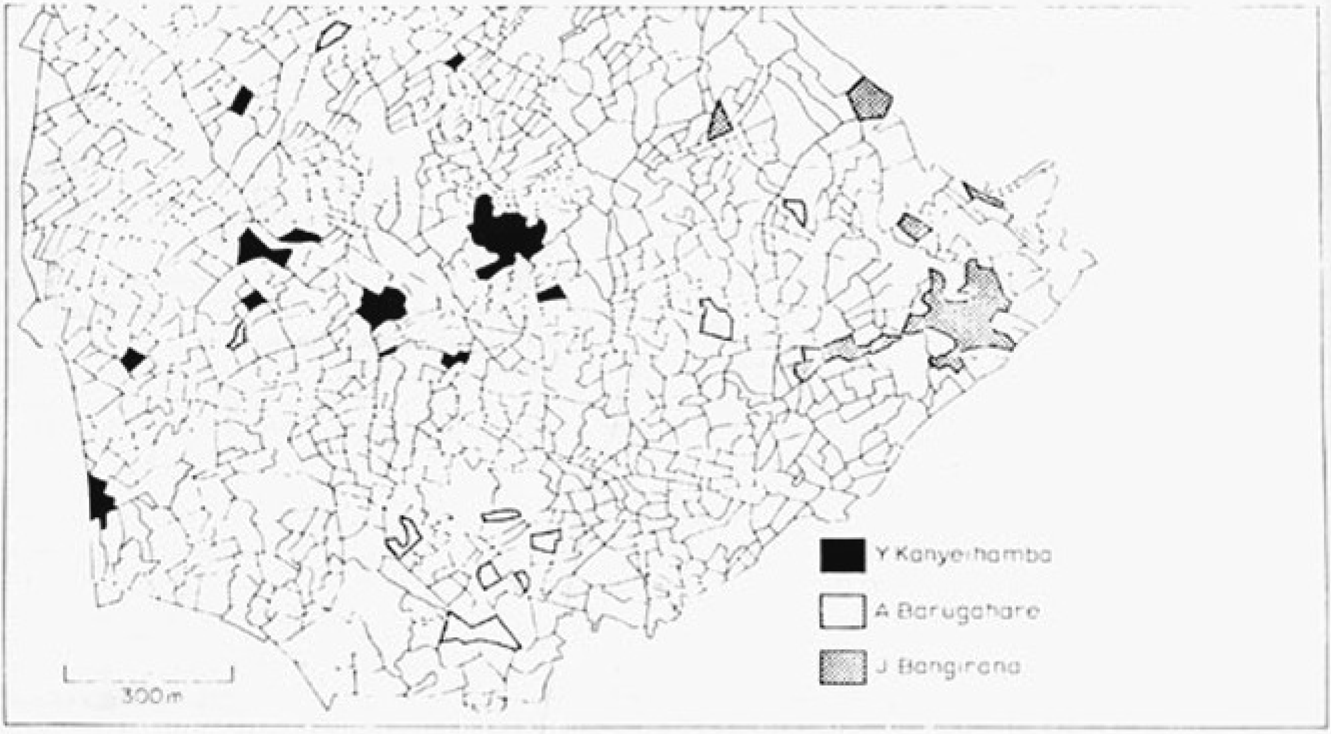


Fig. 50 Land fragmentation in Uganda (from Hudson N. 1981. Reprinted from Soil Conservation, 2nd Ed., with permission from Cornell Univ. Press, Ithaca, and B.T. Batsford, London, to use copyrighted material)

N. 1981; Figs. 32, 33) and are not adaptable to any type of cultivation, except manual.

Soil fertility maintenance through recycling of organic wastes, chiefly crop residues, is a major component of labour intensive continuous cultivation. Thus, short supply of organic wastes can be a serious disadvantage. It may be due to low levels of production (a major problem in many dry-farmed areas), use for other purposes (fuel, feed for animals, fences, roofs, etc.), rapid decomposition, or destruction by termites. Where residue amounts are inadequate, or too low for use as mulches or to be managed in no-tillage systems to enhance water conservation or reduce erosion, alternate practices must be employed if soil fertility is to be maintained and if soil and water resources are to be conserved.

Soil fertility can be sustained through the application of suitable fertilizers or through growing soil improving crops in suitable rotations. While growing such crops reduces the amount of land devoted to food production, their use may be the most economical method of maintaining soil fertility because inorganic fertilizers are expensive (Poulain 1980; Zayed 1980) and may not be readily available.

The use of soil improving crops for maintaining or improving soil fertility in intensive cultivation systems was discussed in FAO (1977c), and by Ayanaba (1980), Sant'Anna (1980), Singh and Balasubramanian (19i3o), and Zayed (1980). Through selecting suitable crops, providing proper inoculants and using good management, sufficient nutrients were returned to maintain or improve soil fertility.

Crops grown for this purpose have a secondary benefit if properly managed: namely, they conserve soil and water resources. Depending on the crop, it may provide good protection against erosion during its growth period and afterwards. Proper management would include keeping as much residue as possible on the surface or incorporating residues with soil to maintain soil organic matter contents.

Crop production potentials

The literature contains numerous examples of the potential for high crop yields from limited areas when soils are intensively managed. Some exceptionally high yields have been obtained in tropical or subtropical locations where a year-round growing season* and adequate precipitation are available, and where intensive cropping practices, such as intercropping, relay cropping, transplanting, rattooning*, etc., were used. Such intensive cropping is very dependent on hand labour. The following are a few examples to illustrate the high levels of crop production that are possible through intensive crop management.

A year-round growing season coupled with use of short-season crops and intensive cropping systems permitted Bradfield (1969) to grow four or more crops per year on the same land in the Philippines. To achieve maximum production with such intensive cropping, he attempted to minimize the time that land was idle. To achieve this goal, he recommended the following practices:

- bedding land to accelerate drying of bed tops,
- keeping tillage operations and volume of soil stirred to a minimum,
- using early-maturing cultivars capable of producing high yields per hectare per day,
- growing rattoon crops when feasible,
- transplanting slow-growing vegetable crops,
- seeding rice directly into unpuddled soil,
- growing some crops each season which can be harvested in an immature state, and
- intercropping whenever possible.

By using some of these principles, Bradfield (1969) grew five crops requiring 413 days of growing season in a 12-month period by inter-cropping. Two major land preparation operations were used each year. Average yields were: rice - 5.0 tons/ha; sweet potato - 25.0 tons/ha; soybeans (dry) - 2.5 tons/ha; sweet corn (maize) - 40 000 ears/ha; and soybeans (green pods) - 6.0 tons/ha. Through such intensive cropping, water resources were effectively conserved and utilized, and the potential for erosion should have been slight.

In another system in the Philippines, Bradfield (1969) produced 22.6 tons/ha of grain on the same land in a 12-month period. Crop yields were: rice - 5.0 tons; sorghum - 5.5 tons; sorghum (first rattoon) - 6.6 tons; and sorghum (second rattoon) - 5.5 tons. The rattoon crops did not require additional land preparation, thus decreasing the labour requirement for crop production and decreasing the time for crop establishment.

Sanchez (1977) reported on an intensive intercropping system established after harvesting rice in Peru. Maize was planted in 1-metre spaced rows, and soybeans on 0.5-metre spaced rows between the maize rows. After 45 days, cassava cuttings were planted in the maize rows. After harvesting maize and soybeans, cowpeas were planted where the soybeans had been, while cassava grew vigourously. The four crops grown on the same land required 266 days. After a 1-month rest period, maize was planted again as before, but upland rice replaced soybeans. After 68 days, cassava was planted in the maize. Maize was harvested after 105 days and rice after 140 days. Groundnuts (peanuts) were planted 5 days after harvesting rice and harvested 3 months later. Cowpeas were grown after groundnuts and before the cassava canopy closed in. The five crops were grown in 367 days. Considering the whole system, nine crops were harvested from the same land in 21 months.

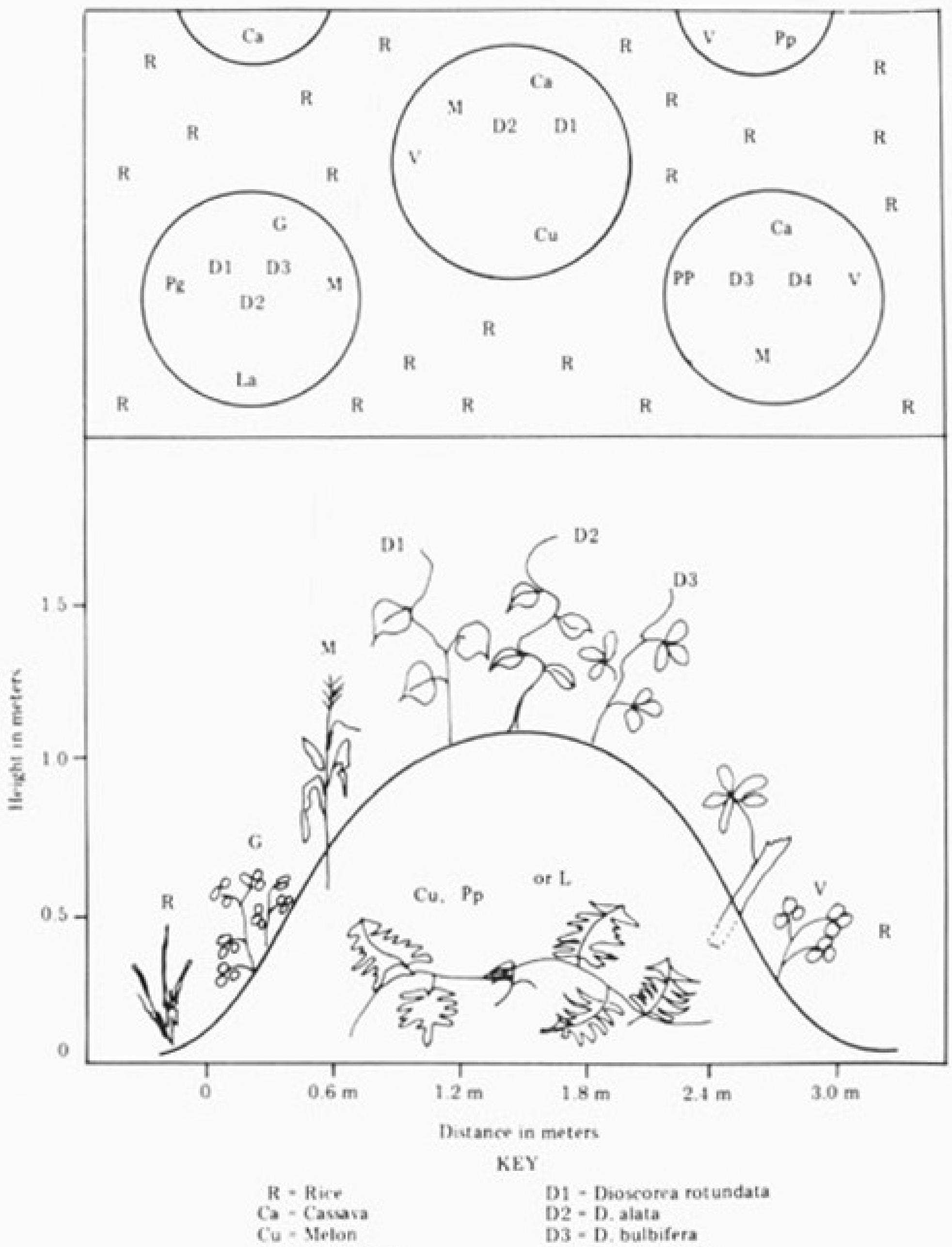


Fig. 51 Spatial distribution of crops on mounds in Abakaliki, East Central State, Nigeria (from Okigbo and Greenland 1976. Reprinted from Multiple Cropping, ASA Spec. Publ. No. 27, page 74, with permission from the Am. Soc. Agron., Crop Sci. Soc. Am., and Soil Sci. Soc. Am.)

To supply a variety of foods for the family, some farmers in Nepal and Indonesia grow 50 to 60 plant species in their homestead areas. Plants grown may include five or six tall-growing trees (coconut or fruit), five or six medium-height trees, five or six shrubs or bushes, four or five root crops, and up to 30 shade-tolerant short-statured or vine-type annuals (Harwood and Price 1976),

Other examples of intensive cropping limited land areas were reported by Harwood and Price (1976), Hildebrand (1976), Okigbo and Greenland (1976) and Pinchinat *et al*. (1976). Some spatially and temporally intensive cropping patterns are illustrated in Figures 51, 52, 53 and 54. Some requirements and further advantages of intensive cropping systems are discussed in Section 4.3.

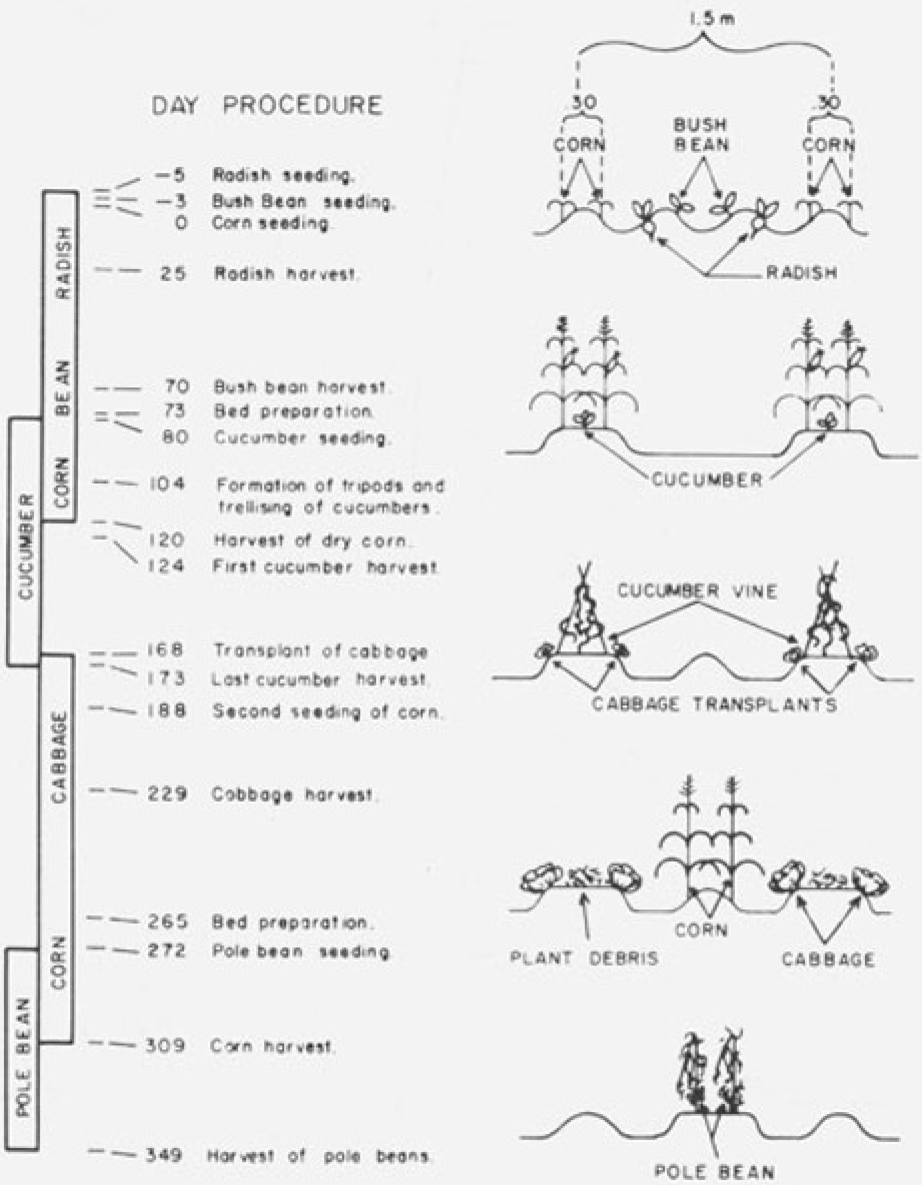


Fig. 52 Basic multiple cropping system developed for El Salvador (from Hildebrand 1976. Reprinted from Multiple Cropping, ASA Spec. Publ. No. 27, page 363, with permission from the Am. Soc. Agron., Crop Sci. Soc. Am., and Soil Sci. Soc. Am.)

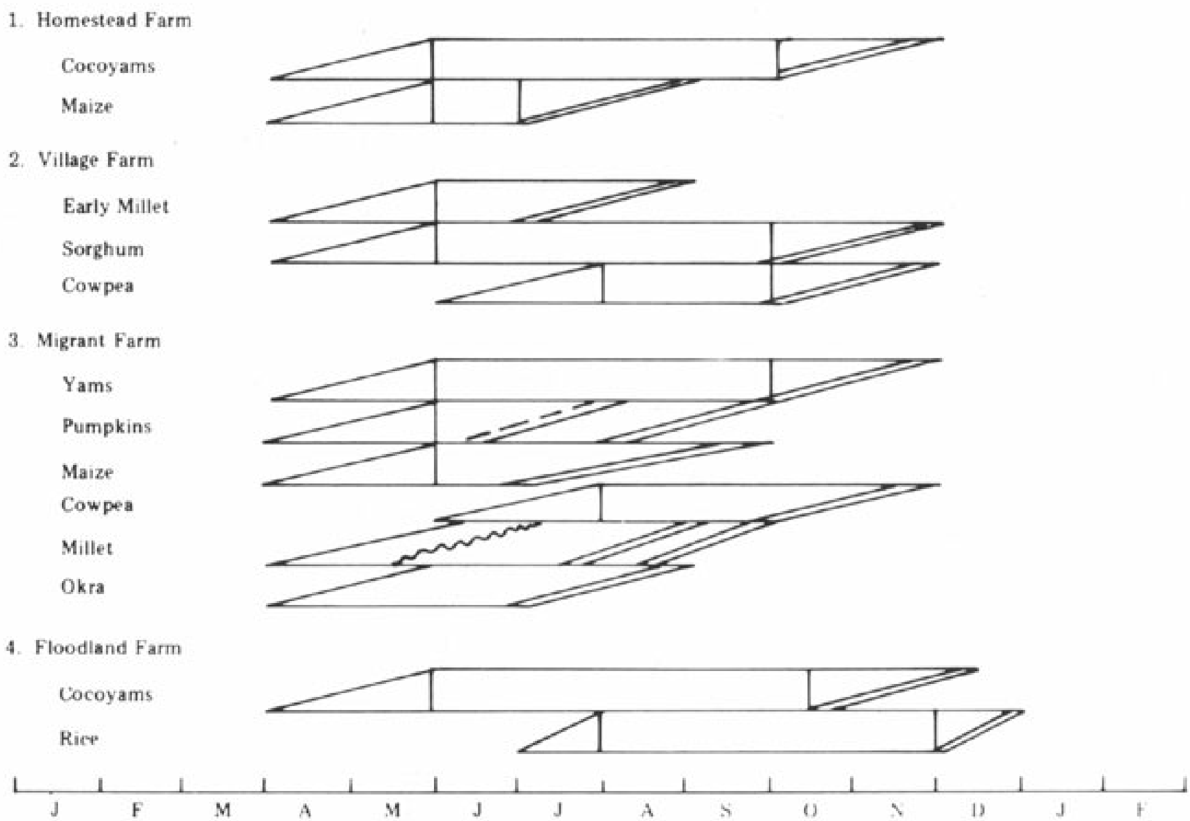


Fig. 53 Cropping schedule and combinations of the Kofyar in Nigeria (from Okigbo and Greenland 1976. Reprinted from Multiple Cropping, ASA Spec. Publ. No. 27, page 81, with permission from the Am. Soc. Agron., Crop Sci. Soc. Am., and Soil Sci. Soc. Am.)

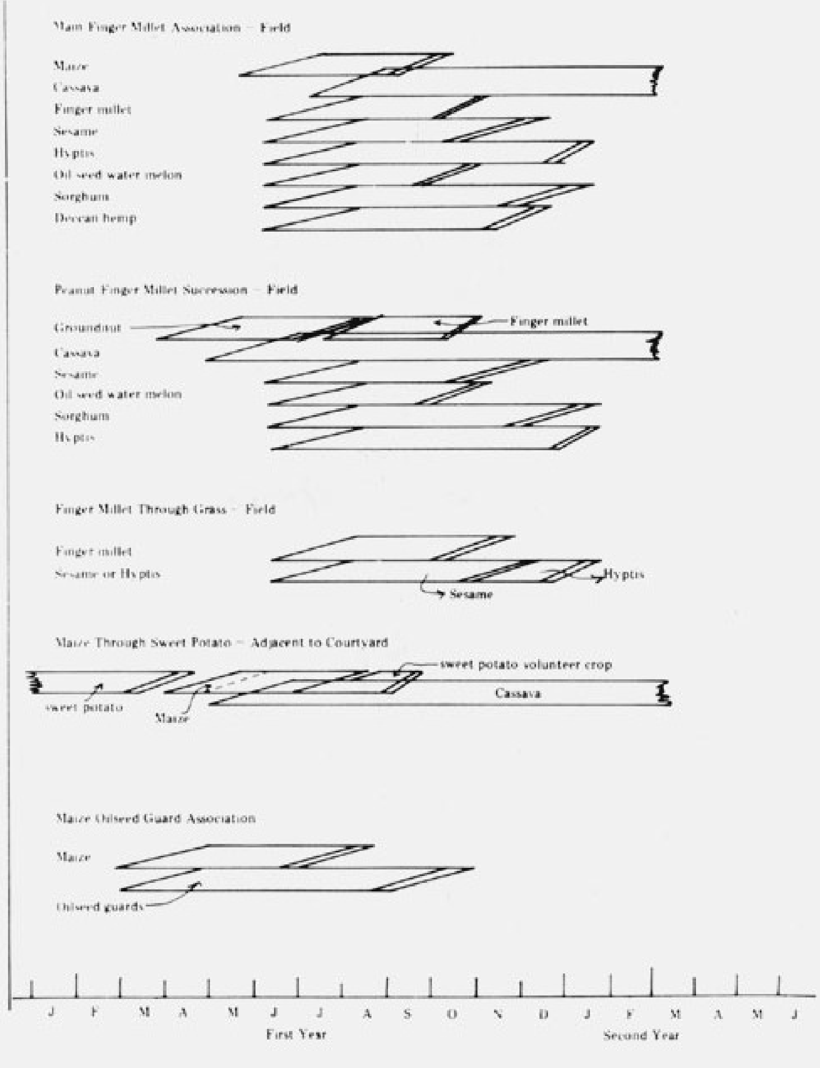


Fig. 54

Crop associations and cropping schedule of the Azande in Congo Kinshasha, southern Sudan, and the Central African Republic (from Okigbo and Greenland 1976. Reprinted from Multiple Cropping, ASA Spec. Publ. No. 27, page 90, with permission from the Am. Soc. Agron., Crop Sci. Soc. Am., and Soil Sci. Soc. Am.)

a. Managing continuous cultivation systems

Extra production labour intensive continuous cultivation, as defined in this report, is an improvement over shifting cultivation and subsistence continuous cultivation, both of which are also labour intensive. However, further improvements in extra production labour intensive cultivation systems are needed because soil and water resources are not effectively conserved and utilized in many instances.

The basic principles involved in having improved practices introduced and adopted in continuous cultivation systems are essentially identical to those discussed for shifting cultivation (Section 3.2.1.vi). These are: the farmer must recognize a need for improvement; the improved practice must harmonize with the existing system, be thoroughly planned, and confirmed to be suitable to the average farmer; and the introduction must be coordinated through and have the full cooperation of all agencies concerned.

With the hoe, cutlass or machette, and spade as the main implements used in labour intensive continuous cultivation systems, the opportunities for improved soil and water conservation through soil manipulation or disturbance are limited to operations that involve mainly the upper 10 to 15 cm of soil. Major land forming operations, such as bench terrace construction by hand labour (Hudson N. 1981), are alternate means of improving soil and water conservation (Fig. 55). This practice along with other major land forming practices are discussed in a subsequent section.

Manipulation of the upper 10 to 15 cm of soil with hand operated implements may involve a variety of operations such as controlling weeds, mixing or loosening soil, planting, ridging and moulding (Figs. 2, 3, 4, 56, 57, 58). Each has an impact on soil and water conservation.

The value of weed control for reducing plant competition and conserving water is generally recognized and has been previously discussed. Unless weeds are checked chemically, hoes are the major weed control implements in labour-intensive cultivation systems. Besides discouraging weeds, however, hoeing may also smooth the surface, break up or pulverize clods and result in a bare soil surface, which could lead to increased surface sealing, runoff and water erosion, unless the soil is otherwise protected against erosion. Increased wind erosion is also a possibility. Alternatives to hoeing for weed control would be the use of mulches or no-tillage, both of which result in soil and water conservation (see Section 3.2.1). The no-tillage system is discussed in greater detail in Section 3.2.4.ii.

Hoes or spades can be used for soil mixing, loosening and surface shaping. Mixing may be needed to incorporate fertilizers (organic or inorganic), plant residues, or other organic wastes, or to prepare a desirable seedbed.

Fertilizer and crop residue incorporation with soil have been widely promoted, but satisfactory results have been obtained in many minimum and no-tillage studies when fertilizer elements (N, P and K) were applied on the surface. Nitrogen moves readily with water and there was little difference in maize yield when N was applied at rates commonly used in the USA (Thomas in press). Because of the potential for leaching and denitrification, delayed or split applications of N fertilizers were advantageous for maize in no-tillage systems, but not in conventional tillage systems (Frye and Thomas 1979).

Fig. 55 Rice terracing in western Java. Properly designed, constructed and maintained level terraces effectively control erosion by water (FAO photo)

Fig. 56 Workers preparing land for vegetable production, Cape Verde Islands (FAO photo)

Fig. 57 Workers in Togo constructing mounds on which cassava or yams are planted. The mounds provide loose soil and protection against flooding for the crops. Maize is planted between the mounds (FAO photo)

Fig. 58 Soil mounding in India permits the production of crops that do not tolerate flooding. Rice can be grown between mounds (photo provided by B.A. Stewart USDA-ARS)

Surface application of P to bare soils may not be satisfactory because of extreme dessication that sometimes occurs when no residues are present. However, surface application is an easy and efficient method of applying P in minimum and no-tillage systems (Thomas in press). Singh *et al*. (1966) used labelled P to determine the P efficiency when incorporated or applied to the surface of a very low phosphate soil in Virginia (USA) . The results (Table 14) showed that surface-applied P was taken up by maize in a larger proportion and in a larger total amount than incorporated P, especially early in the growing season. Similar results were obtained by Belcher and Ragland (1972) and Triplett and Van Doren (1969). Therefore, surface applications of fertilizers are generally adaptable to systems based on extensive use of hand labour.

Table 14 PERCENT P FROM FERTILIZER AND PERCENT P IN MAIZE PLANTS (from Singh *et al*. 1966)

Days after planting	% P from fertilizer		% P in plant	
	No-tillage	Conventional	No-tillage	Conventional
30	54	16	0.07	0.04
46	43	32	0.18	0.18
60	25	21	0.16	0.13
67	36	37	0.15	0.15

Possible reasons for the good results with surface-applied P in minimum or no-tillage systems include: (1) application of P fertilizer to mulched, undisturbed soil allows minimum contact with soil and, therefore, little opportunity for fixation (Thomas in press); (2) P uptake is enhanced because of increased soil water content at the surface of minimum and no-tillage soils (Mahtab *et al*. 1972); and (3) much of the P absorbed by surface soil is held by metals in organic matter (Hargrove and Thomas 1981) and is, therefore, more labile than when held by clays or hydrous oxides (Thomas in press). In some soils, however, broadcasting and incorporating P is beneficial. One such soil is an Oxisol in Brazil on which all crops and most pasture species produced zero yield without added P. On this soil, banded application of P was inferior to broadcast application for the initial maize crop because the available P in the soil was so low that root development was limited to the soil volume containing P. Therefore, in the banded treatment, plants experienced severe water stress. The recommended procedure for overcoming the severe P deficiency on this soil is to broadcast 140 kg/ha of P (320 kg/ha P_2O_5) initially, then band 35 kg/ha of P (80 kg/ha P_2O_5) before planting each crop, including the first (Sanchez 1977). Following this procedure on such P-deficient soil would require considerable soil disturbance for the first crop, but minimal disturbance for subsequent crops if a minimum or no-tillage system were used.

The results for K are similar to the results for P, except that K deficiencies have been reported in some minimum tillage studies, mainly in association with cold weather and poor growing conditions (Thomas in press). Therefore, K deficiency could be a problem where surface residues result in a cool soil. However, the higher level of K near the surface should permit greater uptake because of the greater concentration of roots in the surface soil when residues are present (Triplett and Van Doren 1969), thus minimizing the adverse effect of the cool soil.

The generally favourable results with surface application of fertilizers in minimum and no-tillage systems lead to the conclusion that major soil mixing is not necessary to incorporate plant nutrients when such tillage systems are used. However, adequate residues must be maintained on the surface to reduce runoff and provide the higher soil water content at the surface to promote root activity and nutrient uptake. Without surface residues and on soils with extremely low P content, incorporation of fertilizers, especially P, should be beneficial.

Soil loosening may be needed to improve water infiltration and plant growth when the soil is compacted or when a surface crust is present. Soil crusting results mainly from soil dispersion and re-orientation of soil particles due to raindrop impact, but may result also from dispersion of low-stability aggregates by irrigation or flood waters, or from deposition of sediments by flood waters. Compaction results from mechanical forces on the surface (due to human, animal, or equipment traffic) and within the soil (action of implements, etc.), and from natural forces, such as soil drying and wetting. Also, some soils have naturally dense layers (for example, fragipans).

A sufficiently compact or dense soil will restrict water infiltration and root growth within the soil. On such problem soils, loosening of the dense layer enhances water infiltration, plant growth, water use and crop yields (Bradford and Blanchar 1977; Burnett and Tackett 1968; Campbell *et al* . 1974; Jensen and Sletten 1965; Mathers *et al*. 1971; Musick and Dusek 1971, 1975; Saveson *et al*. 1961). However, unless a problem layer is present, deep loosening of a soil is usually not beneficial with respect to increased water infiltration or crop yields (Unger 1979; Unger *et al*. 1981). This has been illustrated in many studies involving water infiltration into conventional and no-tillage soils (Benatti *et al*, 1977; Harrold and Edwards 1972; Hays 1961; Johnson *et al* . 1979; Laflen *et al*. 1978; Lal 1974, 1980; Onstad 1972; and others). Besides, water contents are generally higher in no-tillage than in conventional tillage soils. Therefore, higher soil densities are apparently less critical in no tillage soil, except where poor drainage and poor aeration may be problems. Also, higher water contents near the surface suggest that deep rooting may not be as important where no-tillage rather than conventional tillage is practised (Unger 1982a).

Because of the large amount of work required to loosen a soil deeply with hand labour, the use of no-tillage cropping practices on soils susceptible to compaction seems highly desirable. The no-tillage system would be especially beneficial where traffic on the surface is restricted to specified zones and crops are planted between traffic zones. By restricting traffic, deep loosening of soil would not be necessary because soil in planted areas would remain less compacted, thus resulting in favourable crop growth and yields (Gill and Trouse 1972).

The major adverse effect of soil crusts is to reduce or prevent seedling emergence (Grable 1966), but crusts also affect seed germination and plant root growth through reduced aeration (Unger and Stewart 1976) and greatly reduce water infiltraton rates (Fig. 20). Impaired seedling emergence generally requires a mechanical operation to break the crust unless rain is received or water is applied to reduce crust strength. In extreme cases, crops must be replanted, often resulting in crop establishment at a time later than the optimum. Reduced infiltration results in increased runoff and the potential for increased water erosion. Increased wind erosion is also associated with soil crusting. Soil surfaces become smooth as the surface aggregates disperse and become re-oriented, thus leading to a surface condition conducive to wind erosion.

Crusts that impede seedling emergence can be broken by a variety of implements (hoes, forks, rakes, etc.). Usually, only the soil crust above seeds needs to be broken. However, for enhancing water infiltration or roughening the surface to reduce wind erosion, crusts over the entire surface must be broken. Although this can be accomplished with implements used to aid seedling emergence, it becomes a much greater operation and must be repeated after each rainstorm until the crop becomes well established.

Crust formation can largely be avoided by protecting soil against dispersion due to raindrop impact. Surface mulches or residues remaining from previous crops in no-tillage systems harmlessly dissipate the energy of falling raindrops (Unger 1982a). For example, 80 mm of intense rain after planting soybeans, followed by hot, dry winds, caused a dense crust that prevented seedling emergence on conventional-tillage plots. In contrast, a near-perfect plant population was obtained in no-tillage plots (Sanford *et al*. 1973).

A complete cover of surface residues is most beneficial for preventing crusting and thereby maintaining high water infiltration rates. However, where plant residues are limited, concentrating them just over the seed zone should be beneficial for avoiding crusting and enhancing seedling emergence. This could be easily achieved when the crops are planted in rows or some other pattern, but would be difficult where seeds are randomly scattered on the surface and then covered. Whether residues cover the entire surface or only a zone above the seed, they provide for improved seedling emergence not only by decreasing soil crusting *per se*, but also by decreasing the rate of soil surface drying (Mahtab *et al*. 1972; Unger 1978a; Unger *et al*. 1971). Therefore, a lower crust strength that permits seedling emergence is maintained for a longer time than where a soil dries rapidly.

Whereas major loosening of soils to depths greater than 10 or 15 cm with hand implements (hoes, spades, etc.) is laborious, these implements are quite adaptable to various types of surface shaping to conserve soil and water. Examples of practices that retain water on the surface and, therefore, reduce erosion, and which can be installed with hand equipment, include contour ridges and furrows (Fig. 59), tied ridges (dammed or blocked furrows), bench terraces (Figs. 33, 34, 38, 55), intermittent terraces, platforms, reverse-slope terraces and contour bunds. These and other soil and water conserving practices that require surface shaping are discussed in a subsequent section.

3.2.3 Animal-draught and Small Tractor Cultivation

i. Introduction

The era of animal-draught technology for agriculture began about 3000 BC when man learned to harness the animals he had domesticated earlier. The wheel was discovered or invented at about the same time, and eventually led to the development of carts pulled by humans or animals which made handling and carrying of agricultural products easier and more efficient. Other early developments included the use of animals to pull ploughs, harrows, rollers, etc. that were used to prepare seedbeds for crop production. Although

Fig. 59 Workers constructing ridges on the contour to help control erosion in Chile (UN photo, issued by FAO)

improvements were made through the years, no major changes occurred until the development of a “steam traction engine” that provided mobile power for heavy tillage operations on large-scale farms. A further advance was the adaption of internal combustion engines to tractors early in the 20th century (Gifford 1981).

The development of tractors for tillage operations did not result in the elimination of crop production by hand labour and draught animals in many countries. Areas and percentages with the type of power used in developing and developed countries are given in Table 15. Projections are that the total number of draught animals and tractors will increase by the year 2000 in 90 developing countries, but that the percentage contribution of draught animals to total power output will decrease by that year (Gifford 1981). However, draught animals will continue to be a major power source in many countries.

The change from hand labour to draught animals or small tractors (less than 22 to 30 kW (30 to 40 hp)) for performing tillage operations should have little effect on soil and water conservation. Essentially any soil condition achieved by use of animal or tractor power can be achieved by hand labour. The major differences lie in labour required, timeliness of the operations and intensities with which soil is tilled. Use of animal and tractor power is also important for installing the major soil and water conservation practices that are discussed under “Supporting Practices” (Section 5).

Fig. 60 Oxen pulling a wooden plough in Afghanistan. Use of animals for tillage permits farmers to produce crops on a larger area and decreases the labour requirements for tillage (FAO photo)

Fig. 61 Ploughing in India (photo provided by O.R. Jones, USDA-ARS)

Table 15 AREA CULTIVATED WITH THREE POWER SOURCES IN 1975 (from Gifford 1981)

Categories of countries	Total	Power source Hand labour	Draught animals	Tractors
Developing countries[1]				
Area covered (million ha)	479	125	250	104
Share (%)	100	26	52	22
Developed countries				
Area covered (million ha)	644	44	63	537
Share (%)	100	7	11	82
World total[1]				
Area covered (million ha)	1 123	169	313	641
Share (%)	100	15	28	57

[1] Excluding China.

Historically, draught animals have been used to increase the area cultivated, but not necessarily to increase yields from a unit of land. In Gambia, for example, it was estimated that the use of oxen permitted a 20 to 25 percent average increase in the cultivated area for groundnut (Gifford 1981). No yield increases were reported.

ii. Effect on labour

In addition to permitting cultivation of a larger area, tillage is accomplished more rapidly with draught animals than with hand labour (Figs. 60, 61). Gifford (1981) reported that 60 manhours of labour were needed to plough a hectare of land with animals and 500 man-hours if done by hand. In Malawi, 54 hours of hand labour were needed to prepare a hectare of land whereas the task was accomplished in 32 hours with a team of oxen (Oluwasanmi 1975). Hand labour for tillage was greatly reduced, but the amount of physical effort required of a farmer in a given hour or day when using draught animals for cultivation was not greatly affected. The farmer still had to guide the implement and walk the same distance as the animals, which required considerable physical effort (Gifford 1981).

As for draught animals, the use of tractors permits the ploughing of larger areas on a more timely basis and with less labour input for ploughing than where hand labour is used exclusively (Fig. 62). With plentiful land, extending the area under cultivation will extend the total labour requirement because of additional labour needed for planting, weeding, harvesting and threshing crops on the additional areas. In Thailand, the labour requirement increased from 20 to 31 man-hours per hectare when tractors rather than buffaloes were used for ploughing before the onset of monsoon rains. In another Asian country, introduction of small tractors (2-wheel) resulted in an increase in labour absorption for agriculture from 204 people/100 ha before use of tractors to 243/100 ha afterwards. Introduction of tractors resulted in multiple cropping and more continuous employment than was possible when only one rice crop was grown each year, as was the case when buffaloes were used for ploughing (Voss 1975).

Fig. 62 Tillage with tractors on small farms in Japan. Use of tractors decreases labour for tillage, permits more timely tillage, and increases the area that can be tilled by a farmer (FAO photo)

iii. Effect on timeliness and type of operations

Use of animals or small tractors rather than hand labour for tillage affects soil and water conservation through such factors as timeliness of weed control, seedbed preparation and crop establishment, quality of seedbed preparation, and depth of soil loosening.

a. Weed control

Weeds compete with crops for water, nutrients and light; therefore, they must be effectively controlled if crops are to attain their potential yield under the prevailing environmental conditions. Examples of yield losses due to weeds are illustrated in Tables 5 and 6.

Weeds can be controlled by cultural methods and herbicides, either singly or in various combinations. They can also be checked by preventing their establishment or eliminating those that have become established. In this section, the emphasis is on timeliness of weed control by cultural methods.

Weeds use soil water that could subsequently be used by a crop. However, soil water is also lost by evaporation when a soil is ploughed. Consequently, a balance between weed growth (water use) and tillage frequency must be achieved to obtain optimum water conservation. Delayed weed control increases water use by plants whereas frequent tillage of moist soil increases water loss due to evaporation. Under conditions of excessive soil water, delayed weed control could help lower the soil water content. However, if weed control is delayed too long, weeds may become difficult to eliminate and cause subsequent tillage and planting problems.

The effects of time of weed control on water conservation in a semi-arid region were determined by Lavake and Wiese (1979). Controlling weeds at 4, 10, 17 or 24 days after emergence with sweep tillage or by repeated sweep tillage at 2-week intervals during the fallow period significantly affected soil water content at wheat planting in a wheat-fallow-sorghum system. At sorghum planting, the differences were not significant, but soil and water content tended to be lower when tillage was delayed until 17 or 24 days after weed emergence (Table 16). For both crops, water contents at planting were similar when tillage was performed at 4 or 10 days after weed emergence or at 2-week intervals. Grain yields also were similar for these treatments. Delaying weed control until 17 or 24 days after emergence resulted in lower water contents at wheat planting and significant yield decreases for both crops. Because repeated tillage did not increase water content or yield, tillage can be delayed until weeds use more water than is lost by evaporation, thereby decreasing the time and energy expended for crop production. Similar results were reported by Wiese (1960).

Table 16 EFFECT OF TILLAGE FREQUENCY AND TIMING DURING 11-MONTH FALLOW ON TILLAGE OPERATIONS, SOIL WATER CONTENT AND GRAIN YIELDS IN A WHEAT-FALLOW-SORGHUM SYSTEM (from Lavake and Wiese 1979)

Tillage treatment	For wheat crop			For sorghum crop		
	Tillage operations Av.No.	Soil water at planting[1] cm	Grain yield kg/ha	Tillage operations Av.No.	Soil water at planting[1] cm	Grain yield kg/ha
Every 2 weeks	10.3	11.8 a[2]	567 ab[2]	10.6	9.0 a[2]	2 410 ab[2]
Days after weed emergence						
4	5.3	11.4 a	629 a	6.1	9.0 a	2 600 a
10	4.3	10.7 ab	583 ab	5.1	8.9 a	2 530 a
17	3.6	9.7 b	564 ab	4.0	8.4 a	2 100 bc
24	2.7	9.1 b	500 B	4.0	7.9 a	1 900 c

[1]Plant available water determined to a 1.2 m depth.
[2]Column values followed by the same letter or letters are not significantly different at the 5% level (Duncan Multiple Range Test).

Besides affecting soil water contents at crop planting time, weed control in growing crops is also important with respect to the amount of water available for the crop. Any water used by weeds reduces the amount available to the crops. Therefore, weed control in the early growth stages of a crop is essential for maximum crop yields (Moody 1974). In systems where animal or tractor-drawn implements are used for partial weed control (crops planted in rows), more timely control could have a major impact on yields. To achieve complete control would require hand hoeing or similar activities to remove weeds from between crop plants in the row. However, cultivating with implements between the rows would greatly reduce the time and labour required to achieve reasonable weed control.

As illustrated in Tables 5 and 6, yield reduction due to weed competition depends on the crops grown. Timeliness of weed control is a major factor also (Moody 1974); the following are some of his examples:

- maize yields on plants kept weeded for the first 30 days after planting were only 5 percent lower than on plots kept weeded for the entire growing season. Similar results were obtained with soybeans and cowpeas, but yams had to be kept weeded for 3 months to hold yield losses to 5 percent. Whereas weeds appearing in maize, soybeans or cowpeas after 30 days or in yams after 3 months would have a minor effect on yields, they could harbour pests and cause harvesting problems;

- uncontrolled weeds in maize for the first 12, 20 or 30 days after seeding decreased yields by 3, 12 and 22 percent, respectively. In cowpeas, weeds caused no appreciable losses until 30 days after emergence. Further evaluations showed an average yield reduction of 11 percent when cowpeas were weeded once at 3 weeks after emergence, and negligible losses if the crop was weeded at 1 and 4 weeks after emergence. For soybeans, weeds growing in the crop for 10 days caused a 10 percent yield reduction; not controlled for another 10 days, they caused another reduction of 10 percent;

- delayed weeding due to the slowness of hand labour can decrease yields of maize and soybeans by 40 to 50 percent on the area where weeds are controlled the latest. The example assumed that a farmer with 3 hectares of land to hoe started at 20 days, and 5 days was required to hoe each hectare;

- weeds are less competitive when they emerge in a well-developed crop with an extensive root system and enough plant canopy to shade the soil. However, certain weeds grow so rapidly and are so competitive that late weeding may be required in some crops.

The above examples illustrate the importance of timely weed control, the different responses for different crops, and different responses for the same crop grown under different conditions. Consequently, no generalized recommendation can be made that is applicable for all situations. However, weed control is important to obtain maximum yields, and use of animal or tractor-drawn implements can achieve weed control in a more timely manner, thus permitting crops to use some of the water that would otherwise by used by weeds.

Although weedy plants provide protection against erosion, the improved crop growth and yields resulting from good weed control can indirectly result in improved soil conservation. Through better growth of the crop, soil is less subject to erosion than where plant growth is sparse. In addition, greater yields may make it economically feasible for the farmer to adopt and use sound conservation practices.

b. Seedbed preparation and crop establishment

As for weed control, timeliness of seedbed preparation can have a major effect on water conservation, crop establishment and subsequent use of soil water or precipitation for crop production. Except for some crops in high rainfall tropical regions where year-round crop production is possible, most crops have an optimum time for planting because of limitations due to such factors as length of frost-free period, daylength, soil and air temperature, solar radiation, rainfall distribution, irrigation water availability, and potentials for insect and disease problems.

To minimize the potential for yield losses due to planting at a sub-optimum time, seedbeds should be ready whenever conditions are optimum for establishment of the given crop. This can be achieved by performing major tillage operations for seedbed preparation well before the optimum planting date. This may require that tillage be performed under relatively dry soil conditions, especially in regions having distinct low and high rainfall seasons. At some locations, light showers during the dry season are beneficial for seedbed preparation before onset of the rainy season (Bart 1979). Final seedbed preparation can then be achieved without major delay at the start of the rainy season, thus resulting in more timely crop establishment and the potential for using growing season rainfall more efficiently for crop production. Such early seedbed preparation and crop establishment is conducive to water conservation in several ways. One is the control of weeds during the non-cropped period, which was discussed in subsection ‘a’. A second involves loss of soil water by evaporation when soil is stirred during the tillage operation.

Tillage at the end of the previous rainy season may result in substantial soil water evaporation if the soil is relatively wet. However, much of this water would evaporate, even if tillage were not performed. Therefore, tillage at that time would not substantially increase water losses by evaporation and would be less detrimental than tillage near or at planting time. In addition, early tillage has reduced water losses from below the tillage layer in some soils (Bolton and De Datta 1979; Hundal and De Datta 1982; Jalota and Prihar 1979; Monnier 1975; Papendick *et al*. 1973) and has permitted greater water infiltration when rains occurred during the non-cropped period (Lindstrom *et al*. 1974; Massee and Siddoway 1969).

By ploughing under millet straw at the end of the 1971 rainy season, Monnier (1975) created a barrier that reduced evaporation of water remaining from the previous rainy season. Groundnuts, which were then planted after 25 mm of rain, survived a 55-day drought and yielded 1500 kg/ha with only 376 mm of total growing season rainfall.

A third method of water conservation resulting from early seedbed preparation is the more effective use of growing season rainfall for crop production. In the Philippines, early seedbed preparation (at the start of the dry season) permitted Hundal and De Datta (1982) to seed the first rice crop in dry soil before the onset of the rainy season, then transplant a second rice crop within the rainy season. This doubled rice cropping intensity during the rainy season and nearly tripled yields as compared to those obtained with traditional farmer practices in Southeast Asia, which involved a weedy condition during the dry season.

Seedbed preparation at the end of the previous wet period allowed Bolton and De Datta (1979) to establish a crop 3 weeks earlier than when the soil was prepared at the onset of the following rainy season. Earlier crop establishment by dry-planting in a previously prepared seedbed was also reported by Krantz *et al*. (1978). Early crop establishment is especially beneficial where the rainy season is short and rainfall is limited. Monnier (1975), for example, reported that early planting and quick weeding made it possible for crops to take full advantage of limited water supplies when there is a short and poor rainy season. Through use of these practices, several crops yielded well despite 5 years of drought during the 6-year period (Table 17).

Table 17 CROP YIELDS IN SENEGAL FROM EARLY PLANTING AND QUICK WEEDING TO TAKE FULL ADVANTAGE OF SHORT AND POOR RAINY SEASONS (from Monnier 1975)

Crop	Minimum yield kg /ha	6-year average yield kg /ha
Maize	3 030	3 130
Groundnuts I	2 050	2 550
Groundnuts II	1 510	2 240
Cotton	1 250	1 420
Sorghum	2 000	2 380

Besides permitting the growth of two crops during the rainy season as previously mentioned, earlier crop establishment also has the potential for increasing production from crops by permitting the use of species that are better adapted for using water during the longer growth period. Examples include long-season sorghum cultivars that have higher yield potential than short-season ones, and indeterminate species or cultivars that continue growth or production as long as conditions remain favourable (forages, some vegetables and fruits, etc.).

With favourable growing conditions in Texas (USA), grain yields of hybrid sorghums increased an average of 227kg/ha for each extra day to the half bloom growth stage (Dalton 1967). Thus, long-maturity hybrids (about 74 days to half bloom) had a grain yield potential of about 7300 kg/ha whereas short-maturity hybrids (about 66 days to half bloom) had a yield potential of only about 5500 kg/ha. However, short to medium-maturity hybrids are better adapted and often yield more than long-maturity hybrids where the growing season is short or where the water supply (soil water, rainfall or irrigation) is limited). For any cropping area or region, length of growing season and availability of water are important factors affecting the selection of species or cultivars to be grown to optimize the use of water and obtain favourable yields. Selection of a cultivar whose critical growth stages coincide with periods of highest rainfall probability (in semi-arid regions) increases the potential for most efficient water use and favourable yields. Cultivars with highest yield potential under favourable conditions may not yield as much as other cultivars if water is limited.

A fourth water conservation benefit resulting from timely seedbed preparation is the opportunity to grow a crop during the most favourable growth period. Where a seedbed is not or cannot be prepared before onset of the rainy season, it may not be possible to establish a crop until near or at the end of the rainy season, thus resulting in the soil being bare during the rainy season. Runoff and soil losses are much greater from non-cropped bare soil than from cropped land during the rainy season (Bhatia et al. 1979; Krantz et al. 1978; McDole and Vira 1979, 1980; Verma et al. 1979).

c. Seedbed preparation operations

Seedbed preparation under dry-soil conditions is difficult if not impossible with hand labour, but can be achieved with animal-drawn implements and with tractors, especially if the major tillage is performed at the end of the rainy season or if advantage is taken of the light rains during the dry season. The type of tillage used at a given location depends on numerous factors including producer preferences, crop to be grown, power sources, implements available, climate, soil characteristics, and pest problems. Each has a direct influence on soil and water conservation, both directly and indirectly through interaction with the other factors. Except for power sources and equipment available, the above factors as well as some others were discussed in Section 3.1 and will not be further discussed. In this section, it is assumed that the producer has chosen not to use the no-tillage system, which has been previously considered and is discussed in more detail in Section 3.2.4.ii.

Animals generally used to power farm implements are buffaloes, oxen, horses, mules, donkeys and camels (Gifford 1981). Because of differences in size and strength of these animals, the power provided varies widely. Some examples reported by Hopfen and Biesalski (1953) are given in Table 18.

Table 18 POWER PROVIDED BY DRAUGHT ANIMALS (from Hopfen and Biesalski 1953)

Animal	Weight range	Draught power	Average speed	Power rating	
	kg	kg	m/s	kg m/s	hp
Light horse	400 - 700	60 - 80	1	75	1.0
Bullock	500 - 900	60 - 80	0.6 - 0.85	56	0.75
Cow	400 - 600	-[1]	-	30	0.4
Mule	200 - 300	-	-	50	0.7
Donkey	120 - 250	-	-	30	0.4

1 Not reported.

The normal strength of an animal is proportional to its weight, corresponding roughly to one-tenth of it (Hopfen and Biesalski 1953). Therefore, large differences in power are available, depending on the animal used. When the soil is moist, most animals can provide enough power for some type of tillage, especially on light-textured soils, but on heavy clays and under dry-soil condition’s, tillage with one animal is difficult if not impossible. Using a team of animals provides more power (Gifford 1981; Hopfen and Biesalski 1953), but there is some loss of total power when a team is used as compared to when the animals work separately (Hopfen and Biesalski 1953). Because of the difficulty in ploughing a dry soil, ploughing at the end of the rainy season when soils may be somewhat moist is a definite advantage when animals are used for tillage.

As with animals, ploughing with small single-axle tractors and power tillers, usually in the 3.7 to 13.4 kW (5-18 hp) size range, is not possible in heavy or dry soils. These tractors and tillers have been used successfully for wetland rice and some horticultural crops (Gifford 1981), and when other less harsh soil conditions prevailed. Even somewhat larger tractors, in the 13 to 22 kW (18-30 hp) size range, have not proved adequate to till such soils. Only tractors of

Fig. 63 Animal-drawn seed drill in Libya (FAO photo)

Fig. 64 Transport cart in India (photo provided by O.R. Jones, USDA-ARS)

more than 30 kW (40 hp) are capable of ploughing heavy and dry soils without major difficulty. However, these larger tractors are seldom adapted to individual small farms (Gifford ly81) and are not considered in the discussion in this section.

Farmers in developing countries usually have a very limited selection of implements and machines to use with animals and small tractors. Typical implements or machines available are one or two types of ploughs, a disk or spike-tooth harrow, sometimes a seed drill, and invariably a cart or trailer (Figs. 5, 6, 16, 60, 61, 62, 63, 64). A trailer is often considered an economic necessity with tractors because it allows the farmer to utilize the tractor also for transporting goods and people, often at a greater profit than obtained from field work (Gifford 1981).

Initial tillage is usually the most intensive operation for seedbed preparation. Depending on prevailing conditions, initial tillage may be used to loosen, mix or invert the surface layer of soil. While all implements loosen soils, loosening without mixing or inversion can be accomplished with breaker and furrowing ploughs with shares (Hopfen and Biesalski 1953), and with chisel and subsurface sweep ploughs (De Brichambaut 1970). Breaker and chisel ploughs, and furrowing ploughs to some extent, are not very effective for controlling weeds, but provide for excellent soil loosening (Hopfen and Biesalski 1953; De Brichambaut 1970), and retain crop residues and other materials on the soil surface. Sweep ploughs also loosen the soil, control weeds (especially when used in conjunction with rodweeders), and maintain a large percent of residues on the soil surface. The sweep plough, also called a stubble mulch plough, is discussed in more detail in a later section.

Soil-loosening implements when used on dense, compacted soils result in increased water infiltration and, therefore, reduced erosion by water. Protection against wind erosion is achieved when soil-loosening implements produce a rough, cloddy surface (Fig. 34). A rough, cloddy surface is often the only effective wind erosion control method in dryland farming regions where residue production by crops is low or where residues are removed for other purposes.

In some cases, emergency tillage is performed to control wind erosion at or soon after planting a crop. The objective is to roughen enough of the field so that it is not erodible. Chisels spaced at intervals of 1.2 to 2.4 m are most effective for emergency tillage. Success depends on the timeliness of the operation and the amount of clods brought to the surface (Kelley 1970). Such emergency tillage to control wind erosion has even been used in established wheat without seriously damaging the crop (Lyles and Tatarko 1982).

In preparation for crop planting, ploughs that mix or invert the surface soil layer are often used to incorporate crop residues, manure, fertilizers and other materials; to control weeds; or to loosen soil. Soil mixing is usually accomplished with disk harrows, disk ploughs or rotary tillers. These implements control weeds quite effectively, and disk implements are particularly useful where tree roots, stumps or rocks are in the soil. The disks easily pass over these objects whereas tine (chisel) or share-type implements could be damaged (Hopfen and Biesalski 1953).

The mixing-type implements, especially when used on dry soils and when few or no residues are present, result in soil pulverization and breakdown of clods (Fig. 65). Use of these implements, therefore, tends to increase the potential for erosion, both by water and by wind. Increased water erosion results from rapid sealing of

Fig. 65 Tandem disk harrow. Disk harrows pulverize dry soil and, therefore, can lead to water and wind erosion problems (photo provided by C.R. Fenster, University of Nebraska)

Fig. 66 Land smoothing in Bangladesh (FAO photo)

the surface when rains occur. Increased wind erosion results from the large amount of fine materials on the relatively smooth surface created by these implements (Siddoway 1963; Woodruff and Siddoway 1973) . Maintaining adequate clods on the surface of sandy soils to control wind erosion may be especially difficult because these soils usually have low cohesiveness (Harper and Brensing 1950).

Surface soil inversion is achieved by use of mouldboard or disk-type turning ploughs (Hopfen and Biesalski 1952). When performed at optimum soil water contents and with proper implement adjustments, such ploughing usually results in effective weed control, soil loosening, and residue, manure and fertilizer incorporation.

Water conservation by use of these implements results from controlling weeds and from loosening the surface layer if it is dense and compacted. Increased water infiltration due to soil loosening may reduce water erosion. Provided the ploughing results in a rough, cloddy surface, wind erosion could also be reduced. However, inverting the surface layer exposes moist soil to the atmosphere, thus increasing water losses due to evaporation. Furthermore, surface residues, when adequate amounts are present, are usually more effective for controlling water and wind erosion than are the clods produced by soil inverting tillage. Finally, soil inverting tillage is energy-intensive tillage. Therefore, the advantages and disadvantages of such tillage should be carefully evaluated where soil and water conservation are major objectives. In general, soil inverting tillage should only be used for seedbed preparation where other types of tillage do not produce the desired soil condition, where water conservation is not of major importance, and where erosion is not serious or where it can be controlled by other means.

An important goal of tillage between crops, in addition to soil and water conservation, is to prepare a desirable seedbed in which to plant the crop. An important attribute of a desirable seedbed is the presence of moist soil in the seed zone with a continuous zone of firm, moist soil underneath (Hanway 1980). However, such a condition is seldom achieved by the initial major tillage operation, especially when it loosens the soil deeply or results in a rough, cloddy surface. If the initial tillage is performed well in advance of planting, natural forces (soil wetting and drying, freezing and thawing, rainfall and wind, etc.) will help create an improved seedbed condition. In many cases, however, secondary tillage is needed. Various types of implements have been developed for secondary tillage, but in developing countries, the choice is limited mainly to harrows (disk, tooth, comb, etc.), cultivators (tine, sweep, rotary), power tillers, rollers and drags (various types) (Figs. 6, 62, 65, 66) (Gifford 1981; Hopfen and Biesalski 1953; Oluwasanmi 1975). Improved seedbeds resulting from secondary tillage increase the potential for favourable crop establishment and subsequent growth and yields. These in turn result in more efficient water utilization and improved soil conservation.

Depth of soil loosening

Tillage with hand labour is limited to a depth of about 10 to 15 cm. Tillage to greater depths is possible as more power becomes available through the use of animals or tractors. However, deep tillage (to depths greater than 25 to 30 cm) is usually impossible with animals or small tractors; therefore, the discussion in this section is limited to depths less than 30 cm.

Any tillage operation should be directed toward alleviating a recognized soil pr0blem or creating a desirable soil condition. Likewise, depth of tillage on a given soil should be based on prevailing soil conditions and on the requirements of the crop to be grown.

When an impervious layer (ploughpan, hardpan, fragipan, etc.) is present or develops in a soil, tillage to greater than normal depths may be required to disrupt it. In such cases, the results are normally longer lasting and more likely to be profitable than routine deep tillage on most cultivated soils. The effects of deep tillage on heavy clay soils are usually temporary, often disappearing within the first year. Initially, water infiltration and storage. may be increased by deep tillage. However, the cracks and crevices formed by deep tillage disappear after the soil is wetted, and the soil then assumes its original condition (Hanway 1970).

On shrinking and swelling clays, normal drying is about as effective as deep tillage for enhancing water infiltration and storage in the profile. For example, water infiltration into Pullman clay loam, a soil high in montmorillonitic clay in Texas (USA), is appreciable while cracks and other temporary storage volumes are being filled. As much as 7 to 10 cm of water may enter the soil in the first few hours of rainfall or irrigation. Thereafter, the infiltration rate becomes very low (Hauser and Taylor 1964; Taylor et al. 1963) and is little affected by chiselling to depths greater than for normal tillage (Hauser and Taylor 1964).

Where an impervious layer is not present, water storage is more influenced by soil conditions at the surface and by weed control than by tillage depth per se. This has been shown in many studies where no-tillage was evaluated with respect to water conservation. With crop residues or killed sod maintained on the surface, water infiltration and subsequent soil water contents were usually greater than where the soil was tilled, provided weeds were satisfactorily controlled (Harrold and Edwards 1974; Hays 1961; Lal 1974, 1980; Thomas in press; Unger et al. 1971; Unger and Wiese 1979). Without adequate weed control and maintenance of surface residues, no-tillage cannot be expected to nor does it result in water conservation or crop yields equal to those obtained with tillage (Hakimi and Kachru 1976; Hundal and De Datta 1982; Jalota and Prihar 1979; Kamara 1980; Kang et al. 1980; Mahto and Sinha 1980; ODA 1982; Shaalan et al. 1977).

Water storage in soil and crop yields due to different tillage depths (other than no-tillage) have been variable. Gaikwad and Khuspe (1976) reported no effect of tillage depth (8 to 10 cm or 18 to 20 cm) on water retention. Similarly, Rai and Yadav (1979) reported nonsignificant average differences in soil water at planting and wheat yields due to shallow (5 cm) and deep (25 cm) tillage without stubble in India. In the Philippines, soil water contents were not significantly different due to rotary tillage (10 cm deep); ploughing 20 cm deep, then rotary tillage; herbicide treated, mulched, not ploughed; and herbicide treated, not mulched, not ploughed treatments, but tended to be highest for the ploughing, then rotary tillage treatment (Hundal and De Datta 1982).

In another study in India (Verma et al. 1979), runoff during 1974 was 112 mm with 25 cm-deep tillage and 133 mm with 12 cm-deep tillage. The runoff occurred during 12 storms that produced 448 mm of rain. Total rainfall in 30 storms was 610 mm. Deep tillage resulted in a 620 kg/ha maize yield increase over that obtained with shallow tillage (2180 vs. 1560 kg/ha). When a mulch was added after planting maize, runoff was 73 and 69 mm, and yields were 2030 and

2450 kg/ha with shallow and deep tillage,respectively. The higher yields with deep tillage were probably partially the result of lower runoff. However, if water supply alone was the yield limiting factor, then a greater yield response should have resulted from the mulched treatments. Runoff with mulch was only 55 and 62 percent of that without mulch for shallow and deep tillage, respectively. Mulching provided more water, but a slightly lower yield increase than that obtained with deep tillage.

Hakimi and Kachru (1976) evaluated the effects of ti1lage type and depth on barley grain yields on a calcareous silty clay soil at Shiraz, Iran. A no-tillage treatment was also included in the study and resulted in the lowest average yield (Table 19). The low yield due to no-tillage was attributed to weeds, but no herbicide had been applied. Additionally, the plot area was ploughed, then fallowed for 1 year before initiating the study. Highest yields were obtained with the field cultivator treatment, and were attributed to better water infiltration, lower soil bulk density, more extensive root growth and lower weed populations as compared to the other treatments. The higher average yield with shallow tillage was attributed to better conservation of subsurface water, which contributed to more extensive root development than with other depths of cultivation.

Table 19 EFFECTS OF TILLAGE TYPE AND DEPTHS ON AVERAGE BARLEY GRAIN YIELD, 1973-l975 (from Hakimi and Kachru 1976)

Tillage type	Tillage depth - cm			
	5	15	25	Average
		kg/ha		
Mouldboard plough + disc	2 780	2 490	2 440	2 570 bc[1]
Disk	2 490	2 160	2 320	2 320 c
Field cultivator	3 200	2 750	2 620	2 860 ab
Field cultivator + disk	3 180	3 100	2 780	3 020 a
No-tillage	-	-	-	1 830 [2]
Average	2 910 a[1]	2 630 ab	2 540 b	

1 Row or column means followed by the same letter or letters are not significantly different at the 5% level of probability (Duncan’s New Multiple Range Test).

2 Not included in statistical analysis because depth effect was absent.

Results somewhat different to those of Hakimi and Kachru (1976) were reported by Papendick et al. (1973), who obtained greater water conservation with 11 cm-deep tillage than with 6 cm-deep tillage. This was attributed to increased resistance to water flow from moist layers to the atmosphere and to increased thermal insulation of the moist soil by the dry-soil mulch. The greater water content resulted in more rapid wheat seedling emergence and development.

Possible reasons for the different water conservation and yield responses to depth of tillage include soil differences, initial water contents, type and time of tillage, environmental conditions and crops grown. The variable results support the earlier recommendation that prevailing conditions (soil, climate, crop, etc.) must be carefully evaluated when planning tillage depths because tillage deeper than needed for establishing a good seedbed will seldom be beneficial with respect to water conservation and crop yields. Where relatively deep tillage is used (below the seed zone), the initial operations should be deepest. Then subsequent tillage should be progressively shallower so that a firm, moist seedbed is available at crop planting time (Hanway 1970).

iv. Problems related to the introduction of animals and tractors for tillage

The introduction of animals and tractors for tillage in developing countries is fraught with many problems. They include or are related to government policies and priorities, social and economic conditions, infrastructure, education, attitudes, availability of animals and tractors, feed for animals, animal husbandry, insects and diseases, fuel and other supplies for tractors, and availability of spare parts for implements and machines. Each has a direct or indirect influence on the use of animals or tractors for crop production and, therefore, on soil and water conservation to some extent. However, a detailed discussion of most of them is beyond the scope of this report, where the discussion is limited to a few of the economic problems and to the effects of animals in the crop production system on soil and water conservation. More detailed reports on these and other problems have been made by Carpenter and Ahmed (1970), Curfs (1976), FAO (1975), Gifford (1981), and others. Although important with respect to economic conditions and use of animals, it is assumed that satisfactory actions have been taken to resolve the other problems, which will not be further discussed.

a. Economic problems

With respect to use of animals or small tractors for tillage to conserve soil and water, the major economic problems are related to availability of capital or credit, of suitable land areas of sufficient size, and returns on the investment.

The need for capital or credit is low for subsistence and labour intensive cultivation systems because most labour is supplied by the farmer or family members and the implements used are simple. The need for capital or credit, however, increases with the introduction of animals or small tractors into the cultivation system. Capital or credit is needed by the farmer to acquire the animals or tractor, to acquire satisfactory implements, to provide feed or fuel (including other requirements) for the animals or tractor, and to cover other production expenses such as fertilizer, seed and cost of conservation practices, if used. These expenses must be covered until sufficient income is derived from harvest and sale of products from one or more crops.

Poor economic conditions prevail in many countries as a whole and, in particular, for many small-scale farmers. Therefore, it is often difficult if not impossible for farmers in those countries to amass sufficient capital or obtain sufficient credit to make the transition from subsistence or labour intensive cultivation to animal-draught or small tractor cultivation. Consequently, efforts of various governments and international agencies or organizations may be required to supply the necessary capital or credit to achieve widespread introduction of animals or small tractors for crop production in developing countries (Carpenter and Ahmed 1970; Curfs

A major deterrent to a farmer achieving an improved economic condition is the small, irregularly shaped and fragmented tracts of land owned or operated in many developing countries (Figs. 48, 49, 50) (Carpenter and Ahmed 1970; Hudson N. 1981). Total income from such land holdings is often inadequate to acquire or support the use of animals or small tractors. Although some soil and water conservation practices are applicable to such land, others are difficult to apply and impractical. Their use, however, could be: achieved through consolidation techniques, corporate organizations, or cooperative systems (Carpenter and Ahmed 1970).

The responses by farmers to proposals for corporate, cooperative or consolidated systems have not been entirely unfavourable in areas where they have been studied. The farmers' lack of knowledge of the systems, their individualistic nature and their natural suspicions have been the major causes for their reluctance to accept them readily. In general, however, farmers have expressed the most interest in the consolidated approach for which the aim is to integrate, reshape and improve the size of the farmers' units of ownership (Carpenter and Ahmed 1970). By providing farmers with a unified, better-shaped tract of land (Fig. 67), production efficiency should be improved, which could result in improved economic conditions so that animals or small tractors could be acquired. The larger, better-shaped tracts would also be more suitable for applying improved practices for soil and water conservation, thus minimizing land degradation and, hopefully, achieving greater food production.

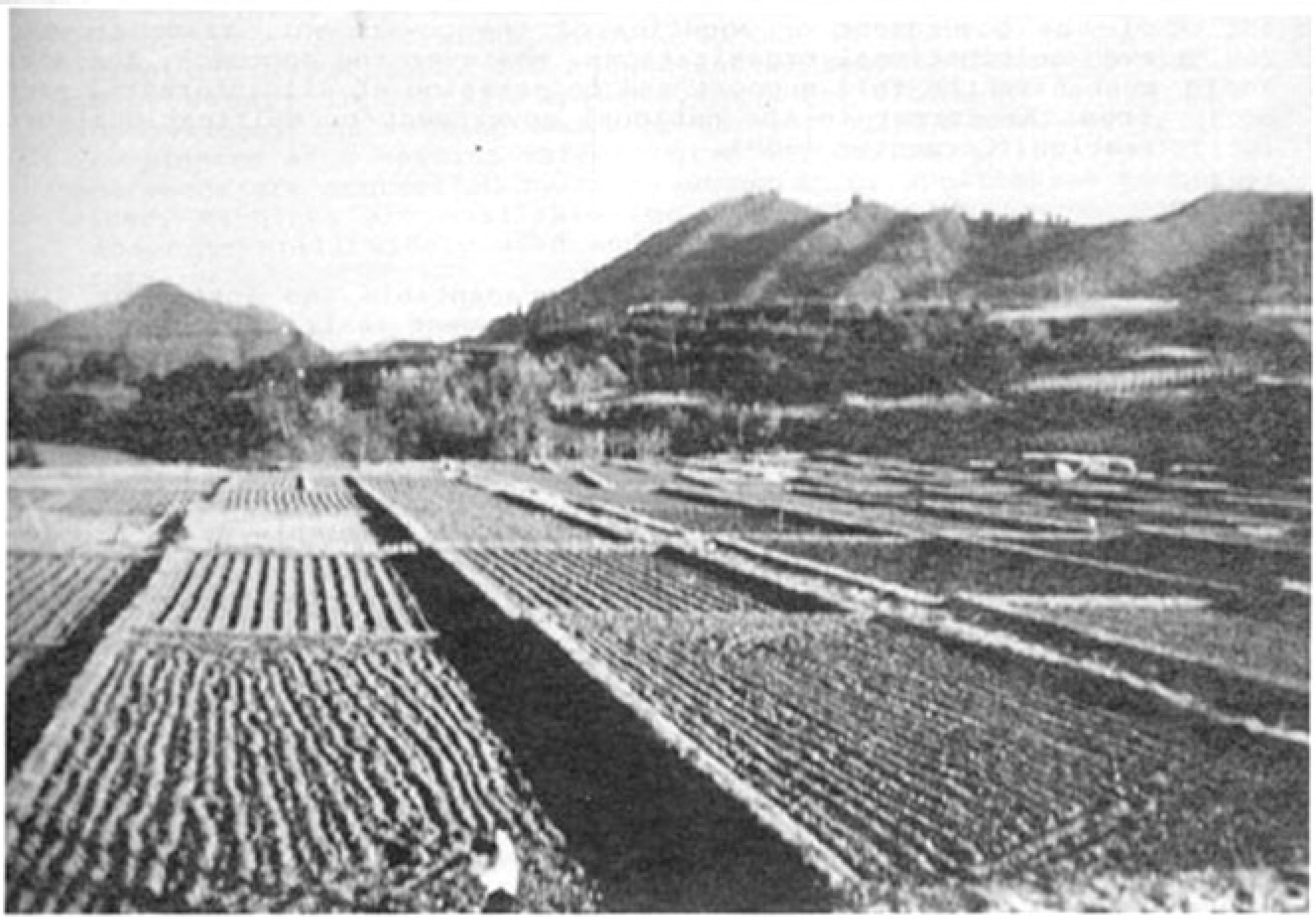


Fig. 67 Uniform layout of small tracts permits efficient use of land and equipment (photo provided by T.V. Hohle)

In some instances, however, even with land consolidation, individual tracts of land may not be large enough to apply effectively all necessary conservation measures. Therefore, joint efforts by all concerned may he required to obtain the greatest benefits from the consolidation process. Some examples include: designating certain areas for grazing, others for cultivation; applying conservation measures (terraces, etc.) across property lines; constructing water storage reservoirs at the most suitable sites, but providing water to the entire system; and constructing roads at the most desirable locations. Undoubtedly, the key to success of such a project is that individual incentive must be maintained (Carpenter and Ahmed 1970). Therefore, all farmers must appreciate the improvements being made, have a part in the overall system, and yet maintain their individuality.

Assuming that adequate capital or credit is available and that land tracts are of sufficient size, a final condition must be satisfied before use of animals or small tractors for cultivation can be adopted. That condition is the opportunity for a satisfactory economic return on the investment. The farmer simply must be convinced that he will advance economically by making the transition from a labour-intensive to an animal-draught or small-tractor cultivation system.

To obtain beneficial returns on the investment, the farmer must grow adapted crops that yield well and for which there is a market. Research may be needed to identify the best adapted crops and cultivars, and this information must be interpreted and provided to the farmer. Establishment of markets may entail action on the part of the government or agencies of the government, trade groups, or even multinational organizations. Whatever the approach, the actions must have the full support and cooperation of all interested parties from the farmer to the national government or multinational organization (Carpenter 1980).

Animal problems

Assuming that draught animals are adaptable (no insect or disease problems, no animal handling or management restrictions) and readily available, there are still some major problems associated with using animals for crop production, and these have a notable effect on soil and water conservation.

Animals require feed, and the feed is usually produced on the farm. Therefore, land that could be used for food production must be diverted to fodder, unless other land is available. This problem is especially important in regions having high populations and limited areas of arable land.

Besides the feed requirement per se, it is required nn a year-round basis whereas production may be seasonal or intermittent. Therefore, feed must be gathered, stored until use, and later fed to the animals, which results in an increased labour requirement and potential storage problems.

In addition to the continual feed requirement, water must also be supplied on a year-round basis, which is yet another problem to overcome. Water may be plentiful in some regions, but critically short in others, especially during the dry season. 5urface water storage facilities are often poor or non-existent, thus requiring that water for animals be drawn from wells or cisterns, again resulting in additional labour.

Undoubtedly the greatest problem with respect to soil and water conservation due to the use of animals results from complete removal of all above-ground plant materials for use as animal feed. The materials may be removed directly by grazing or foraging animals, or be gathered by the farmer for later use as feed. In either case, ton little plant material remains for effective soil and water conservation. In addition, complete removal of plant materials also removes plant nutrients. Unless these are returned as manure or fertilizer is applieb, a cycle of nutrient removal, fertility decline and lower crop production sets in, which can result in severe land degradation (Le Houérou 1976; Rauschkolb 1971). However, if manure and other waste materials are returned, soil fertility can be maintained quite effectively (see Section 3.2.2.ii.a). The fertility requirements with animal-drauqht or small-tractor cultivation should be similar to those for labour-intensive cultivation because crop yields are usually not increased when animals or small tractors are used for tillage (Gifford 1981), except when better timinq of operations can be achieved by use of tractors.

3.2.4 Modern High-technology Cultivation

i. Introduction

Modern high-technology cultivation (MHTC) systems, as used in this report, refer to those systems in which most crop production operations are performed with fuel-powered machines, like tractors (includes self-propelled machines such as harvesters, balers, etc.) and associated implements and machines, with the aid of chemicals (herbicides, insecticides, etc.). Labour is limited mainly to the operation of machines, but a substantial amount of hand labour may be necessary in certain systems for some crops to reduce plant populations, for weeding and crop harvesting. In most cases, crops are planted at a seeding rate to give the desired plant population, and weeds are controlled by cultivation or by application of herbicides. Machines are available for harvesting many crops, but hand labour is still widely used and even necessary for harvesting some crops.

a. Adaptability

The MHTC systems are adaptable to a wide range of farm sizes, from those suitable for relatively small tractors (30 to 37 kW or 40 to 50 hp) to those for one or more tractors in the high-power class (approximately 370 kW or 500 hp). In the latter cases, which are normally large farms or highly commercialized operations, the farms may cover thousands of hectares. In contrast, most farms in developing countries are quite small.

The scale of operation should have relatively minor effect on soil and water conservation, provided comparable technology is available and used, and provided that tractor and implements are properly matched to each other and to farm size. However, when poorly managed, large-scale operations are more likely to be subject to soil and water conservation problems, as is discussed later.

A major advantage of MHTC systems is that field operations can be accomplished rapidly when conditions become favourable. For example, a hectare of land can be ploughed in one hour or less with an adequately sized tractor and matching plough, whereas up to 60 man and animal-hours would he required with draught animals and 500 man-hours iz done hy hand (Gifford 1981). Such rapid operations are also possible for crop establishment and harvesting, thus allowing these operations to be completed quickly when conditions are optimum.

Dependence on tractor power for ploughing, seeding and harvesting can, however, also be a disadvantage in some situations, especially where wet weather interferes with performing field operations at the optimum time. It may not be possible to execute field operations with tractors in wet weather whereas some operations, such as seeding, transplanting, weeding and even harvesting, could he accomplished under such conditions with hand labour.

b. Energy requirements

The MHTC systems are fuel energy-intensive systems because fuel provides energy for tractors, etc.; is used in the manufacture of tractors and associated implements, herbicides, insecticides, fertilizers, etc.; and is used for such purposes as pumping water, drying grain, etc. When fuel prices were relatively low (before about 1974), the fuel cost for crop production was also low. Because of the low fuel cost and, therefore, relatively low operating expenses, multiple tillage operations, often to an excessive point, were sometimes used for crop production. At present, the high cost of fuel is a major economic factor in crop production, especially in developing countries. While this has resulted in economic problems in many cases, it has also resulted in an increased interest in less intensive tillage systems, some of which are highly effective for conserving soil and water resources (see Section 3.2.4.iii).

c. Equipment requirements

Equipment requirements for crop production are high for MHTC systems because they are intensely mechanized. Types of machines and equipment often used include one or more tractors, one or more implements for primary tillage (ploughs, chisels, disks, etc.), one or more implements for secondary tillage (disks, sweep ploughs, rodweeders, furrowers, etc.), equipment for planting (planters or drills), weed control (sprayers, cultivators, rotary hoes, etc.), harvesting (combines, mowers, rakes, balers, etc.), and transport (trailers, carts, trucks). The entire array of equipment would not be needed by a farmer in a developing country who concentrates on production of a few crops. However, as more crops are grown, different types of equipment may be needed, and investment in it often becomes a substantial part in the overall crop production enterprise.

d. Chemical requirements

Chemicals play a major role in MHTC systems, and are widely used to control weeds and insects and to supply plant nutrients. Chemicals may also be used to control diseases, as a harvest aid, and for preserving stored plant products. The latter, however, are not as widely used as herbicides, insecticides and fertilizers and, therefore, will not be discussed.

Under favourable plant and climatic conditions, one or a few correctly-made applications of herbicides can effectively control weeds that would normally require one or more tillage operations and, in many cases, many additional hours of hand labour. For example, three to four tillage operations were required for weed control during fallow in a wheat-fallow-sorghum cropping system in Texas (USA) (Unger and Wiese 1979). Equivalent or better weed control was achieved by one application of atrazine and 2,4-D. In addition, more water was stored in the soil and the potential for erosion was minimal with herbicidal weed control because crop residues were maintained in the soil surface. At current prices in the USA, it is more economical to use herbicides than tillage in such and similar cropping systems (Allen and Wiese 1981). This, however, may not be the case in some developing countries, especially where labour is plentiful and where herbicides are expensive and several applications are required (Moody 1974). The latter may be a serious problem in tropical regions where weed growth is luxuriant. Where weeds must be removed from the planted row, hand labour is often required, especially if herbicides are incompatible with the crop being grown (Moody 1974).

All crops produced by a cultivation system are subject to infestation and various types of damage by insects at some time during the plant s life cycle. Insects may damage planted seed, seedlings, established plants and potentially harvestable products (grain, fruit, forage, etc.). Depending on the time and extent of damage, crops may need to be replanted or the entire production may be lost.

When replanting is required, soil is subjected to potentially greater water and soil losses due to additional exposure of moist soil to the atmosphere (greater evaporation), delay in crop establishment which leaves the soil bare for a longer time, and poor plant growth and development due to planting at a suboptimum time. A11 factors could result in lower harvestable yields and residue production and, therefore, indirectly affect soil and water conservation through lower economic returns to the farmer and directly through lower amounts of crop residue to be managed. Crop damage at later stages when replanting is not practical could have similar adverse effects on soil and water conservation.

Especially damaging with respect to soil and water conservation are infestations of insects that devour most or all plant materials at a time when conditions are not suitable for establishing another crop because of climatic or seasonal limitations. Examples are the devastating infestations of locusts or grasshoppers which generally occur during dry seasons when most soil water has been depleted and rainfall probabilities are low. The resultant bare soil may be subject to wind erosion during the remainder of the dry season and to poor water infiltration and potentially high water erosion when rainfall occurs.

Although a cultivation system may have some effect on insect infestations (Daniels 1975; Musick and Beasley 1978), the potential for insects and other pests is usually more influenced by crops grown” crop arrangement in time and crop arrangement in space than by the tillage method (Litsinger and Moody 1976). The effects of these factors on the potential for pest infestation. are illustrated in Fig. 68. Because crops may be managed differently in different cultivation systems, the potential for insect infestation may, therefore, be indirectly influenced by cultivation systems. For example, many crops may be interplanted or rotated on a relatively small area in shifting cultivation and other labour intensive systems, whereas sole cropping and monoculture are often used in MHTC systems. The latter systems have a high pest potential (Fig. 68).

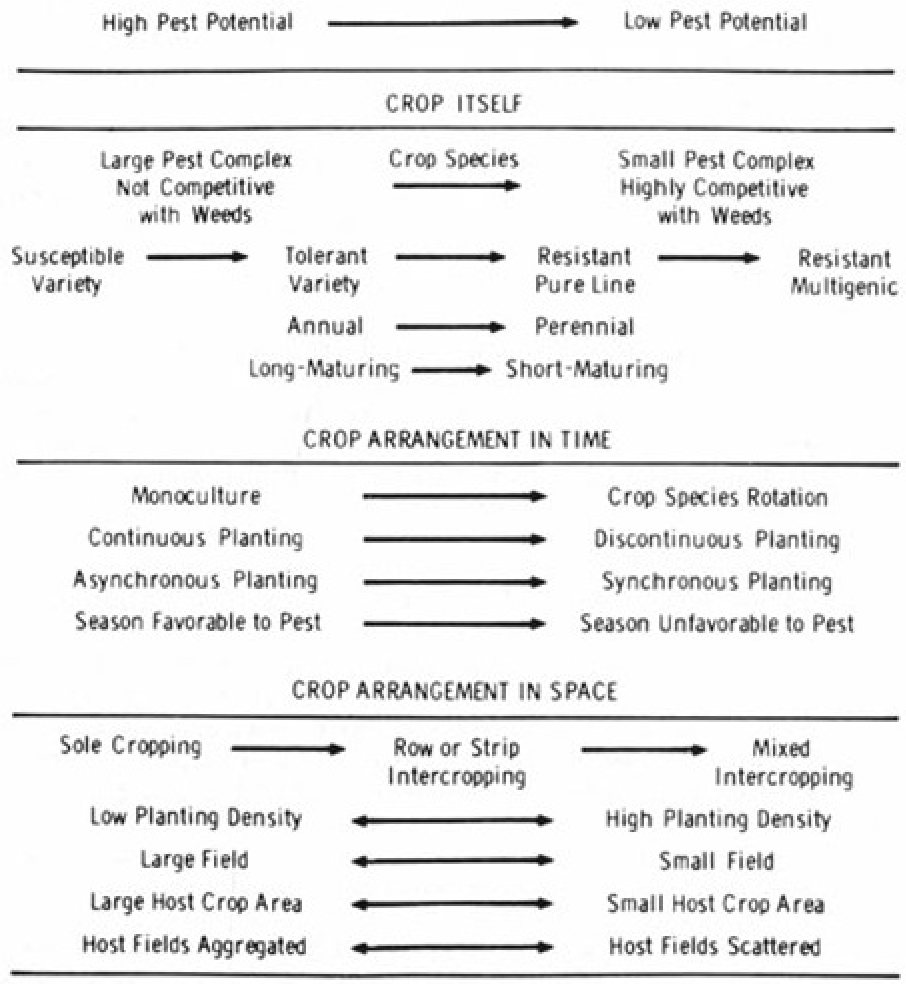


Fig. 68 Kinds of crops and their arrangement in time and space evaluated as to the potential development of pest problems. Some effects are seen to be high in pest potential, some intermediate, and some low (from Litsinger and Moody 1976. Reprinted from Multiple Cropping, ASA Spec. Publ. No. 27, page 297, with permission from the Am. Soc. Agron., Crop Sci. Soc. Am., and Soil Sci. Soc. Am.)

Insects and other pests can be avoided or controlled, at least to some extent, by various management strategies (Litsinger and Moody 1976). However, when infestations occur, they may need to be controlled to avoid major or complete crop losses. The control method used will depend on the insects present, area affected and intensity of infestation. Some insects, for example, may be removed by hand when the level of infestation is low and the affected area is small. This would probably be the case in some labour intensive systems. On somewhat larger areas, spot treatment of affected areas with chemicals applied by a hand sprayer, duster or similar device may be adequate. However, as the level of infestation and size of affected area increases and the availability of labour decreases, insect control relies almost entirely on use of chemicals. Such is usually the case in MHTC systems. Resides heavy reliance on chemicals, the amounts used are usually quite high because the entire field rather than only the affected area is treated and because repeated applications are often made at a predetermined schedule without careful monitoring of insect populations. To avoid excessive dependence nn chemicals, varinus pest management strategies could be used. However, each must be planned and applied under proper conditions and carefully monitored because of constantly changing conditions (Litsinger and Moody 1976).

In shifting cultivation systems, a tract of land is cropped until decreasing soil fertility limits production. Plant nutrients from outside sources are not applied. Some nutrients in the form of organic wastes (manure, crop residues, etc.) may be applied in extra production labour intensive systems. In addition, some chemical fertilizers may be added. The MHTC systems depend heavily on the use of chemical (commercial) fertilizers, even though crop residues and animal wastes may be returned in some systems. Manures are highly beneficial for supplying nutrients (Mathers et al. 1975a), but amounts available may not be sufficient for application to all cropland. Adequate fertilizers not only provide nutrients to enhance crop yields, but they also increase root systems and soil cover, which provide protection against erosion.

Fertilizers are expensive, especially in developing countries and, therefore, should be applied at rates and times compatible with crop requirements to obtain most efficient fertilizer use. To achieve this, various soil and crop characteristics must be known or be determined. Soil characteristics include initial fertility, fertility maintenance capability and soil physical properties. Crop characteristics include differences in nutrient requirements, patterns of growth and nutrient accumulation, adaptability to seasonal variation and to low fertility. In addition, fertilizer requirements may differ if monoculture, rotations, strip cropping, double cropping, rattoon cropping, relay intercropping and row intercropping systems are used (Oelsligle et al. 1976). If inadequate nutrients are available or applied, crops will not yield at their full potential and soil and water conservation efforts may be thwarted. Applying excessive amounts may actually damage some crops and, in addition, will be wasteful of fertilizer, thus unnecessarily increasing production costs.

Effects of mismanagement

With good management and conservation measures, such as bench levelling, steeply sloping lands are intensively cropped in many areas without causing serious soil erosion (Figs. 32. 33, 55). However, the potential for extremely high erosion is ever present, and such erosion occurs if the systems are improperly installed or’ subsequently neglected (Fig. 69). Cropping under such conditions is highly labour-intensive, although animals and small tractors may be used. Large tractors are not practical on such steeply sloping land. However, medium to large tractors (greater than 3U kW, i.e. 40 hp) provide most of the power in MHTC systems, and effective soil and water conservation can be achieved on certain lands when these tractors and associated equipment are properly used. On other lands, supporting practices such as contouring, terracing, strip cropping, bench levelling, etc., are required to reduce soil losses to tolerable levels.

Use of the above practices does not seriously interfere with tillage and other crop production operations when tractors and associated equipment are relatively small (effective operating width of 1-4 m), but larger tractors and equipment can result in inefficient use of

Fig. 69

Poor design, construction or maintenance of bench-terraced land can lead to severe erosion (FAO photo)

Fig. 70 Failure to maintain terraces increases soil erosion (photo provided by H.E. Bruns, USDA Soil Conservation Service)

the tractor, equipment, labour or land. This may result from odd-shaped fields that cause delays in turn-around time, from a poor match between equipment and strip or field widths that causes some areas to be reworked and others omitted, from short rows that require that the tractor be turned around frequently, from having to provide relatively wide turning areas and roads to accommodate the large-sized equipment, and from the generally reduced speed of operations because of the above factors.

To avoid problems, users of large equipment often do not use conservation practices that result in odd-shaped fields, narrow strips or terraces, and in some cases have eliminated those that had been previously installed (Fig. 70). Unfortunately, this has resulted in considerable erosion in many regions, especially where the land is tilled up and down the slope and where the tillage methods used do not afford other means of protection against erosion, such as adequate surface residues, a rough and cloddy surface, and conditions favourable to rapid water infiltration.

Large tractors and equipment are mainly used on large-sized farms and, therefore, the above problems may not be applicable to most farms in developing countries. However, there are relatively large operations in some developing countries and the same problems on a reduced scale are also applicable to smaller farms. Therefore, to achieve optimum efficiency in the use of tractors, equipment, labour and land, and optimum conservation of soil and water resources, regardless of farm size, the sizes of tractors and equipment should be carefully matched to the size of farm or field.

Frequent consequences of using tractors with more power than needed for the equipment being used are excessive speed of operation and tillage to depths greater than required. One example of the relationship between tillage speed and size of soil clods is given in Table 20. Because clods are effective for controlling wind erosion, the slower speed of operation which produced more clods should be more effective for controlling erosion (Gill and Vanden Berg 1967).

Table 20 EFFECT OF SPEED OF OPERATION ON THE SIZE OF SOIL CLODS PRODUCED BY CHISELLING (from Gill and Vanden Berg 1967)

Soil type	Speed of tillage tool km/hr	Clods greater than 19.2 mm in diameter %
Silty clay loam	2.9	31.7
	4.0	30.8
	5.0	28.2
Silt loam	5.0	8.3
	6.1	5.8
	6.9	5.3

The size of clods was also affected by a rotary tiller; as rotor speed increased, individual tines passed through the soil in less time and caused a greater impact on clods. As the impact increased, average clod size decreased even though the size of cut was maintained constant. Average clod diameters were about twice as large at a rotor peripheral speed of 250 cm/sec than those produced at a speed of 500 cm/sec (Gill and Vanden Berg 1967). Excessive soil loosening and pulverization occur also when mouldbnard and disk ploughs are operated at excessive speeds (Stallings 1957). The greater loosening or pulverization at higher speed leaves a soil more susceptible to erosion by wind and possibly also by water.

Tillage to greater depths than necessary is wasteful of energy and could result in evaporative losses of soil water as discussed earlier and, consequently, poorer crop growth and yields and greater erosion. Water losses result from evaporatinn from the loosened soil layer. Because of deeper loosening, more water would be required to fill the soil’s water storage reservoir.

The MHTC systems are geared more toward trouble-free accomplishment of all land preparation, weed control, planting, cultivation, and harvesting tasks than any other cultivation systems. Unless the equipment used is specifically designed for operation where there are large amounts of crop residues (see .Section 3.2.4.iii), these frequently interfere with the performance of various operations. Residues may clog tillage implements, planters and cultivators, intercept herbicides, interfere with the harvesting operation, and affect crop quality. To minimize the potential for these problems, crop residues may be ploughed under at the first operation where inversion-type tillage is practised, or disked several times. To minimize potential problems, residues may be burned (Fig. 42) before any tillage operation is performed, especially if large amounts of residue are present.

Burning or ploughing under crop residues undoubtedly minimizes crop production problems. However, with properly designed equipment, such drastic measures are not always essential. On Pullman clay loam in Texas (USA), residue management practices for fully-irrigated winter wheat had no major influence on performing tillage and seeding operations, crop yields and crop water use. The treatments were: mouldboard ploughing, rotary tillage, disk tillage, lister tillage, and residues burned, then lister tillage (Unger et al 1973). The soil slope was about 0.15%; therefore, the potential water erosion was slight. The potential for wind erosion also was slight because of the nature of the soil and because the crop was irrigated.

On other soils and under other cropping conditions, ploughing under crop residues or burning them and leaving the surface exposed could increase the potential for wind and water erosion, low conservation of water and low crop yields. In addition, burning crop residues accelerates the decline in soil organic matter (Unger et al. 1973), which in itself may adversely affect crop production, and results in losses of nutrients (especially N), which are costly to replace, especially in developing countries.

Where the emphasis is on resource conservation (soil, water, energy, etc.), the protective value of crop residues should be considered and exploited in the crop productive system. To achieve this, residues must be managed, not burned. This is particularly important in dryland agriculture where residue production by crops is usually small and where any protection against soil and water losses is highly important for sustained crop production.

Effect of land division

An important requirement of MHTC systems is that farm size and shape be such that it is economically feasible to use modern equipment and techniques to accomplish the crop production operations and to achieve soil and water conservation. Because tractors and equipment are available in a wide range of sizes, it is usually possible to select a tractor and equipment of suitable size. Difficulty in achieving this, however, may be encountered where farms are small initially or where they have been divided among heirs. Because of repeated divisions and emphasis on providing each heir a tract of land of equal value, the resultant farms are small or of shapes otherwise unsuitable for use of modern equipment and techniques (Figs. 48. 49. 50), both for crop production and for implementing effective measures for soil and water conservation.

Some possible measures of land consolidation for achieving economically-sized farms were discussed by Carpenter and Ahmed (1970) (see Section 3.2.3.iv.a). Unless some form of land consolidation is accomplished where farms are small and irregularly shaped, little or no opportunity exists for introducing MHTC systems. Unfortunately, the existence of these particular farms often makes it economically and physically impossible to achieve effective soil and water conservation.

Clean tillage systems

Definition and history

Clean tillage systems are those in which all plant residues are covered and in which the growth of all vegetation is prevented, except for the desired crop. The residues are usually covered by inversion-type tillage early in the interval between crops (Fig. 71). In some systems, however, residues may be partially incorporated with soil at the first operation, as with disking (Fig. 72), then further incorporated at subsequent operations so that little or no residues remain on the surface when the next crop is planted. Unwanted vegetation is controlled initially by the major ploughing operation and subsequently by one or more forms of secondary tillage, such as disk harrowing, chiselling, sweep ploughing, rodweeding, etc. (Figs. 72, 73, 74, 75, 76, 77). During a crop’s growing season, weeds may be controlled by cultivation, hoeing or application of herbicides.

Use of clean tillage for crop production apparently started when man became aware of competition between weeds and the crops that were being cultivated. Early clean tillage was probably accomplished with crude implements of wood and stone (Shear in press). Centuries later, the plough was developed and introduced for killing weeds and preparing the soil for planting (Duley and Mathews 1947). Although the value of ploughing has been questioned for a number of years (Faulkner 1974), the plough is still the basic tool and symbol of farming in many cases (Duley and Mathews 1947). Only with the introduction of conservation tillage systems has a trend toward less ploughing developed (see Section 3.2.4.iii).

Adaptation

As a general rule, clean tillage systems are adaptable and suitable on lands that have few if any limitations for crop production (Class I land, Table 2). Clean tillage may be adaptable to other classes of land (Class II and III), provided appropriate supporting conservation measures are used and the choice of plants is restricted to those that provide adequate protection against soil and water losses.

Most if not all crops are adaptable to clean tillage systems on

Fig. 71 Mouldboard ploughing land on the contour in the USA. Most crop residues are covered by such inversion-type tillage (Iowa State University photo, issued by FAO)

Fig. 72 Tandem disking to partially incorporate wheat residues

Fig. 73 Ploughing a wheat field with a chisel plough (photo provided by C.R. Fenster, University of Nebraska)

Fi.g 74 Chisel plough with chisel-sweep points

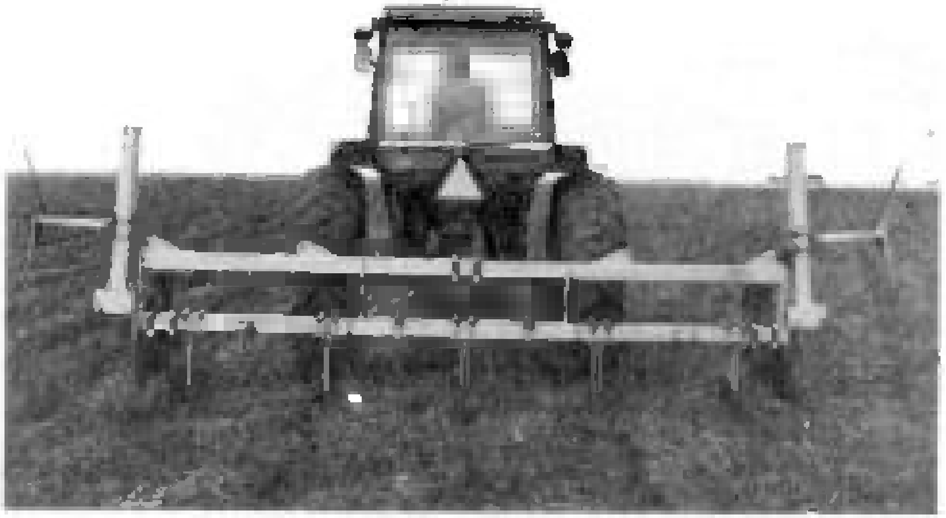


Fig. 75 Sweep implement: the sweeps (Fig. 76) undercut the surface to control weeds and retain most crop residues on the soil surface. The sweeps on each end could be turned down for use with a larger tractor

Fig. 76 Detail of a sweep; distance between wing tips of the sweep is 107 cm

Fig. 77 Sweep-rodweeder: the rod rotates under the surface, thus uprooting weeds

Class I land, provided there are no limitations for reasons other than tillage *per se*. Clean tillage is especially appropriate for crops requiring well-prepared, uniform seedbeds and precise planting, such as many small-seeded vegetable crops. This, however, does not mean or imply that clean tillage is the best system for all crops, even when produced on Class I land. For some crops, precise planting in a residue-free seedbed is not essential, and surface residues retained by other types of tillage may enhance crop production through greater water conservation, less surface crusting, and improved seedling establishment and plant growth as compared with that obtained with clean tillage.

The threat of erosion on Class I land is slight and, therefore, surface residues are seldom required to control erosion on such land. However, on other classes of land, surface residues retained by other forms of tillage provide some or full protection against erosion which cannot be achieved by use of clean tillage. Measurements made for 5 years at Stateville, North Carolina (USA) (Lowdermilk 1953) indicate the effects of various management systems on average runoff and erosion from a soil with 8 percent slope and the time required for 17.8 cm (7 inches) of topsoil to be lost from the fields (Table 21). These results show the potential for high erosive losses from lands other than Class I when clean tillage is used, and the benefits derived from using crop rotations or maintaining a permanent cover of grass or forest on highly erosive soils. Similar results are illustrated in Tables 8, 10 and 12.

Table 21 EFFECT OF LAND MANAGEMENT ON RUNOFF AND EROSION ON AN 8% SLOPING SOIL AT STATEVILLE, NORTH CAROLINA (from Lowdermilk 1953)

Land management	Average runoff %	Average soil loss tons/ha	Time to deplete 17.8 cm of topsoil years
Fallow, clean tillage without cropping	29	143	18
Continuous cotton, clean tillage	10	49	44
Crops in rotation	9	-	109
Grass cover	<1	-	96 000
Forest, burned annually	3.5	0.1	1 800
Forest, not burned	<0.3	-	>500 000

Types and uses of implements

Clean tillage is achieved through a variety of implements such as mouldboard, lister and disk ploughs, which eliminate most or all crop residues at the first operation. Other implements such as disk harrows, chisels and cultivators incorporate some residues at each operation. By using them several times during the non-cropped period, the surface is usually devoid of residues when the next crop is planted. Approximate amounts of residue remaining after each operation with different implements are given in Table 22 (Anderson 1968).

Table 22 EFFECT OF TILLAGE MACHINES ON SURFACE RESIDUE REMAINING AFTER EACH OPERATION (from Anderson 1968)

Tillage machine	Approximate residue maintained %
Subsurface cultivators	
Wide-blade cultivator and rodweeder	90
Mixing-type cultivators	
Heavy-duty cultivator, chisel, and other type machines	75
Mixing and inverting disk machines	
One-way flexible d3isk harrow, one-way disk, tandem disk, offset disk	50
Inverting machines	
Mouldboard and included disk plough	10

In conditions where a clean seedbed is desirable at planting, but where soils are particularly subject to erosion during a part of the interval between crops, use of residue-conserving tillage early in the non-cropped period followed by residue-incorporating tillage late in the period may produce the desired results. For example, chisel, sweep or disk tillage could be used to maintain a large portion of crop residues on the surface during an erosive period that occurs early in the interval between crops. Later, as planting time approaches, disking or lister ploughing (Figs. 16, 35, 36, 78) may provide the desired seedbed conditions. Mouldboard or disk ploughing is seldom desirable as planting time approaches because one or more secondary operations may be required to obtain a proper seedbed.

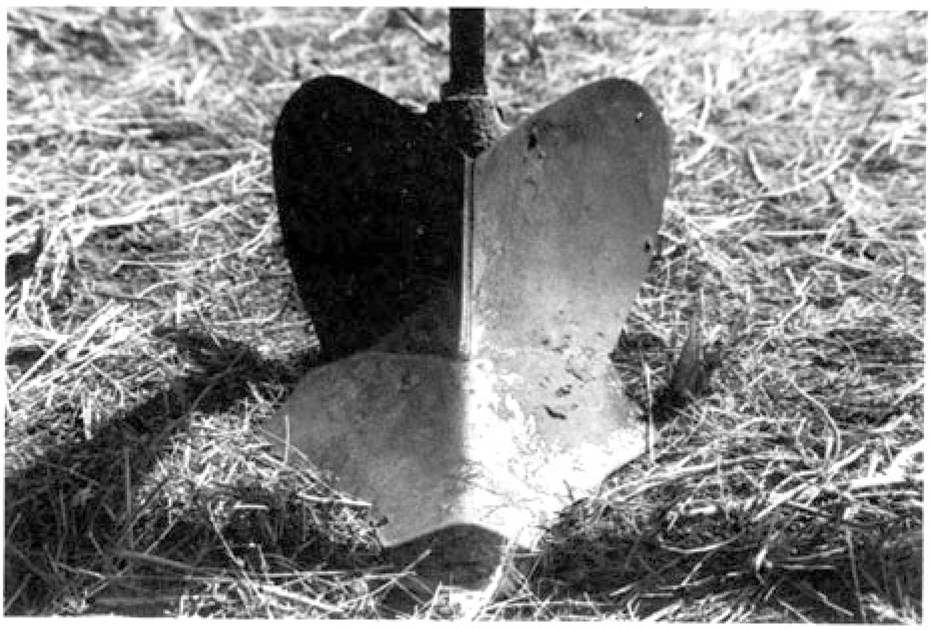


Fig. 78 Lister plough (see Figs. 35 and 36 for lister-ploughed land)

In addition, major tillage near planting time could result in high evaporative losses of water from the tillage layer, thus reducing the amount retained in soil for crop use. Examples of potential water losses from a soil that becomes air dried to different depths are given in Table 23. The amounts of water evaporated would depend on the soil water content at the time of tillage. If the soil water content was at the wilting point and if the soil became air dried, then 1.35, 2.70 and 4.05 cm of water would be lost, and the soil would need to receive those amounts before any became available to plants. The values would be different for other soils, but the results illustrate the importance of avoiding excessive soil water evaporation due to tillage shortly before planting, especially where the potential for rainfall is low at that time. Under some conditions, major tillage late in the season may result in delayed planting or poor seedling establishment and growth because of inadequate water in the soil.

Table 23 WATER CONTENTS AND POTENTIAL LOSSES FROM PULLMAN CLAY LOAM IF THE SOIL BECOMES AIR DRIED T0 THE TILLAGE DEPTH

Soil water level	Soil depth - cm		
	10	20	30
Field capacity (FC) = 36%[1]	3.6	7.2	10.8
Wilting point (WP) = 16%	1.6	3.2	4.8
Plant available (FC - WP)	2.0	4.0	6.0
Air dried (AD) = 2.5%	0.25	0.5	0.75
Plant unavailable (WP - AD)	1.35	2.7	4.05

[1] Percent by volume.

The types of implements used for clean tillage have a major influence on soil and water conservation, which are also influenced by how the implements are used and by soil water contents at the time of tillage. Lister ploughing on the contour is probably the most effective clean tillage method for conserving water and protecting soil against water erosion. Furrows formed by lister ploughing hold potential runoff water on the land, thus providing more time for water infiltration and reducing erosion. Lister ploughing up and down the slope is ineffective for conserving water and controlling water erosion.

At Spur in Texas (USA), which is a semi-arid location, runoff from 1927 to 1952 averaged 7.0 and 5.0 cm with lister ploughing on sloping and contoured rows, respectively (Fisher and Burnett 1953). Erosion was not reported. At a more humid location, runoff from clean tillage watersheds during a 14.0 cm rainstorm on sloping and contoured rows was 11.2 and 5.8 cm, respectively. Soil losses on the respective watersheds were 51 and 7 tons/ha (Table 8).

Differences in runoff and erosion on contoured and sloping-row watersheds result from differences in runoff velocities, with the velocity being lower on contoured watersheds (Unger and McCalla 1980). Similar decreases in runoff velocity are possible by using graded furrows (Richardson *et al*. 1969), which safely convey excess water from fields.

One technique for further conserving water and controlling erosion on gently sloping land where lister tillage is used is to install furrows (Fig. 38). This practice, as well as contouring, is discussed in more detail in section 5.

Unless clean tillage implements such as mouldhoard and disk ploughs, disk harrows, etc. are used in conjunction with other practices for controlling runoff and erosion, it is less important to use them on the contour than it is to use lister tillage on the contour. Whereaas lister or other ridge-building tillage forms furrows to retain or convey water, depending on whether tillage is performed on the contour or up and down the slope, the other implements usually do not create definite furrows and cause relatively uniform surface conditions, regardless of the direction of tillage.

Residues are not retained on the surface when soil inverting ploughs, disk harrows, etc. are used for clean tillage; therefore, factors other than surface residues are important to control runoff and erosion by water. These include amount of residue incorporated, surface roughness, and the portion of the surface disturbed (Wischmeier 1973). The latter, namely strip cropping, is discussed in Section 5. Runoff and erosion are also influenced by water storage in the tillage-loosened plough layer (Larson 1962).

Residues mixed with surface soil or ploughed under are less effective for controlling runoff and erosion than residues on the surface. However, incorporation with soil is better than removal because the incorporated residues tend to increase infiltration and decrease runoff and, hence, erosion. Wischmeier and Smith (1965) showed 40 percent less runoff where maize residues were incorporated by ploughing than where they were removed at harvest. Soil loss was reduced about 12 percent for each 2.2 tons/ha (1 ton/acre) of residues incorporated (Wischmeier and Smith 1978),

On soils where little or no residues are available for incorporation, tillage-induced surface roughness and cloddiness can increase: water infiltration, reduce runoff velocity, and thereby reduce the potential for soil loss (Fig. 34). The surface conditions provide for temporary storage of water on the surface (Table 4), thus providing more time for water infiltration. Runoff and erosion are also reduced because loosening the soil by tillage increases its air-filled porosity, which increases the potential for water storage in the tillage layer. The following example, adapted from Larson (1962), illustrates this potential. If a 17.8-cm-thick (7-inch) layer of soil with a bulk density of3 1.4 g/cm^3 is loosened by tillage to a bulk density of 1.0 g/cm , total porosity increases from about 47 percent to about 62 percent and the thickness of the layer increases to about 24.9 cm (9.6 inches). Potential water storage in the plough layer at saturation was 8.4 cm before ploughing and 15.5 cm after ploughing. Based on a water content of 25 percent by weight at field capacity, the water storage potential in the plough layer between field capacity and saturation was abnut 2.3 cm before and 9.4 cm after ploughing. Such increased capacity would have a major effect on runoff and erosion, provided the storage volume is effectively filled.

Additional storarge volume created by tillage, whether on the surface or within the plough layer, is usually temporary because the loosened layer settles when water is added or when secondary tillage is performed. Secondary tillage also tends to smnooth the soil surface, thus decreasing the potential for temporary water storage in surface depressions (Hays 1961). Surface roughness is further decreased by the dispersive action of raindrops on bare soil, wetting and drying, and freezing and thawing. When rainfall results in a crust or dense layer on the surface, infiltration is greatly reduced and the potential for water erosion is greatly increased. Loosening the crust by cultivation can decrease runoff (Meyer and Mannering 1961), but the operation must be repeated after each major rainstorm until the plant canopy becomes adequate to protect the surface.

Ridges formed by lister ploughing or similar tillage arc effective for controlling wind erosion on sandy soils, provided the ridges are constructed perpendicular to the direction of prevailing winds and soils are sufficiently stable to prevent soil movement from ridge tops into furrows, which would reduce the effectiveness of ridges for controlling erosion (Fig. 79). Ploughingg at a suitahle soil water content increases soil rnughening and minimizes the pulverization of clods (Massoud 1975). Where the potential for erosion by wind is much greater than by water, fields should he ploughed perpendicular to the direction of prevailing winds, even though this may result in ploughing up and down the slope.

Fig. 79

Drifting sand trapped in deep furrows (photo provided by D.W. Fryrear, USDA-ARS)

Unless a cloddy, rough surface can be produced with mouldboard or disk ploughs, these implements should not be used where wind erosion is a problem on sandy soils (Massoud 1975). Mouldboard and disk ploughs, however, may control wind erosion on finer-textured soils, provided the soil is left in a rough, cloddy condition. Disk harrows, one-way disks, etc. may not produce a sufficiently rough surface to control wind emission, hut effective control can be achieved by using chisel ploughs that bring clods to the surface. While not usually considered clean tillage implements, chisels would be suitable in clean tillage situations where weeds are not a problem or have been controlled by herbicides. Chisels can also he used to produce a rough surface where this was not accomplished by previous tillage with other implements.

Implements that help control wind erosion on an emergency basis are those that can be used to create rapidly a roughened soil surface. These include chisels, rotary hoes, sand fighters, etc. (Fig. 74, 80), which either bring cloods to the surface or break the surface crust to provide a roughened or cloddy soil surface, and are discussed in more detail in Section 6.

Fig. 80 Rotary hoe used to break surface crusts to enhance seedling emergence and to roughen the soil surface to control wind erosion

Advantages

Advantages that have been attributed to using clean tillage systems as compared to others include less troublesome performance of cultural operations (tillage, planting, cultivating, spraying, etc.), improved weed control, improved crop establishment, better insect control, better plant disease control, greater soil nutrient mineralization, and higher crop yields.

Without a doubt, residues (from a previous crop and from weeds) when present at adequate levels interfere with the performance of some implements and the accomplishment of cultural operations unless suitable implements for the given conditions are used. Therefore, it follows logically that use of clean tillage practices will minimize those problems where suitable implements are not used.

The major problems in the accomplishment of cultural operations are associated with residues which clog implements and interfere with implement penetration into soil before a “clean” soil condition is achieved. All cultural implements (ploughs, planters, cultivators, etc.) are subject to clogging by residues. However, the problem is most severe when implements are not equipped with coulters or disks to cut residues, when large amounts of lonse residues are on the surface, and when the implements are poorly designed nr have clearances inadequate to permit satisfactory operation in residues.

To minimize cultural problems associated with residues, initial tillage in a clean tillage system is usually a residue-incorporating operation. However, to make residues manageable at the first tillage, they may be shredded, chopped, disked and, in extreme cases, even burned (Figs. 42, 72). After the pre-tillage operation, inverting (mouldboard, disk or lister) or mixing-type (one-way disk, disk harrow, tandem disk, rotary tiller, etc.) implements either cover all residues for greatly reduce the amount con the surface.

When inverting implements, often equipped with a coulter, are used for the initial operation, subsequent tillage may be with disk harrows, drag harrows, cultivators, or sweep ploughs, depending on implements available, weed problems and desired seedbed condition. If the initial operation adequately covers the residues and subsequent weed growth is not too severe, later operations can usually be accomplished without any serious clogging problems. Clogging may, however, occur if secondary tillage is too deep or is performed before residues have decayed.

The type of secondary tillage implement used where a mixing-type implement was used for the first operation depends on the amount of residue remaining on the surface or extent of weed infestation. Where large amounts of residue or weeds are present, a second major incorporating operation be required. However, if most residues were incorporated and the weed problem is not severe, secondary tillage can be with implements similar to those used after an initial operation with an inverting implement.

Once a “clean” soil condition has been achieved and a satisfactory seedbed has been established, subsequent planting and pest control operations can usually be accomplished without major difficulty. A clean, well-prepared seedbed permits uniform planting, good germination, and uniform and rapid seedling establishment, provided other factors such as soil water, temperature, aeration, seed-soil contact, surface conditions (crusts), density, erosion and pests are favourable or adequately controlled (Unger and Stewart 1976). Uniform and rapid crop establishment can result in soil and water conservation because a plant canopy which shields the soil against raindrop impact and erosion, both by water and wind, is produced more quickly than where crop establishment is slow or delayed because of the need to replant the crop.

Pest control methods in clean tillage systems vary, depending on the type of pests present. Weeds are probably the most common pest and are controlled by cultivating, hoeing and spraying with herbicides. In general, cultivating and hoeing are accomplished more easily in clean tillage areas than where residues are present. Likewise, application of herbicides for weed control is affected by soil surface conditions. For maximum effectiveness, soil surface-applied herbicides should be uniformly placed on the entire surface. Uniform application is achieved more easily on residue-free soil than where residues are present because they may intercept some herbicides, thus leaving some areas of soil untreated. In Indiana (USA), for example, maize residues covered 85 percent of the soil surface and intercepted 30 percent of applied atrazine. Many areas under the residues remained untreated (Richey et al. 1977).

Some herbicides must be incorporated with soil for them to be effective. Herbicide incorporation is usually achieved with disks, rotary tillers and rolling cultivators (Fig. 81). Ploughs that invert the surface are less effective because they mix herbicides with soil only slightly. Chisels and sweep ploughs also cause little mixing of herbicides with soil (Unger and McCalla 1980). Mixing is usually easier in the absence of surface residues.

The effectiveness of herbicides applied directly to weeds (contact herbicides) should be little affected by tillage systems. While surface residues, if present, would intercept some of the herbicide, complete coverage with herbicide is generally not required to achieve control of weeds. Where maximum coverage is required, a residue-free condition resulting from clean tillage would result in more effective weed control. Regardless of weed control method,

Fig. 81

Rolling cultivator being used to incorporate herbicides. This implement also effectively controls weeds on furrowed land, such as after lister ploughing (photo provided by A.F. Wiese, Texas Agric. Exp. Stn.)

effective control is essential to avoid competition between weeds and crops for water, as well as for light, nutrients and space.

A second major type of pest in crop production is insects. Crops are subject to damage by insects from planting to harvest, depending on type of crop and insect. Some insects that spend part or all of their life cycle in soil are affected by tillage method, others are not. According to Phillips and Young (1973),various species of sod webworms, cutworms, armyworms and root aphids[1] were a lesser problem in clean than in non-clean tillage fields. Reports for wireworms are variable with Phillips and Young (1973) reporting no effect of tillage and Musick and Beasley (1978) reporting a lesser problem with clean tillage. The southwestern corn (maize) borer is also a lesser problem with clean tillage or other tillage that uproots the maize crowns which harbour the insect larvae during the winter season. Exposure to freezing temperatures reduces subsequent borer populations (Daniels 1975). Besides tillage system per se , insect problems are also affected by location, previous crops and overall management of the systems (Unger and McCalla 1980).

The effectiveness of chemicals for controlling soil-borne insects would certainly be affected by tillage system (for example, clean vs. no-tillage) because residues could intercept and reduce the amount of applied chemicals reaching the soil. Some insects may also be within the residues themselves. Although the degree of insect control achieved in any tillage system would be affected by type of insect and insecticide, and conditions at the time of application, clean tillage would usually reduce insect populations more effectively because it destroys the residues.

Insects do not directly compete with crops for water, hut have a major impact on water conservation, subsequent use of water by crops and soil conservation. Water conservation, besides being affected by tillage method used to achieve insect control (for example, clean vs. conservation tillage), can also be affected by insect damage, which may result in the need for replanting, poor plant development

[1] See Appendix 5 for scientific names of insect pests.

and destruction of potential plant residues. Where the potential for crop damage by insects is high, clean tillage that destroys insect-harbouring residues would he an advantage because it could eliminate the need for replanting, which could result in greater losses due to evaporation or runoff due to reworkincg the soil or delayed development of plant cover. Also, poor plant development may result from insect damage to roots, stems or leaves, which may result in poor plant growth and inadequate cover to afford protection against raindrop impact on the soil surface, soil dispersion and subsequently high runoff. Some insects do their damage late in the growing season by devouring plant leaves or destroying stems. This reduces the potential for subsequently managing the crop residues for water conservation.

Once insects cause sufficient damage so that normal movement of water into and through plants and other plant functions are interrupted, then plant water use, growth, development and yield are usually reduced. Under such conditions, soil water potentially available for the crop is not effectively or fully used. Although the remaining water is potentially available for a later crop, it does reduce the potential for storing additional water and, therefore, results in decreased water conservation in general.

Soil conservation due to insect damage is affected by essentially the same factors that affect water conservation. Replanting and delayed or poor plant development result in conditions favourable to erosion, both by wind and water, for a longer time. Poor plant growth and destruction of plant materials by uncontrolled insects may result in inadequate plant cover for suppressing erosion and inadequate residues to be later managed for effective erosion control.

As for insects, diseases may affect crop production at any stage of a plant's life cycle, depending on types of disease organisms and the plant's susceptibility to diseases. Some diseases affect seeds and seedlings, others established plants or the harvestable product. Clean tillage systems aid in controlling plant diseases (Boswell and Gricher 1981; Cook et al. 1978 ; Kronstad et al. 1978), but there is also evidence that disease problems generally are similar with clean and other tillage systems (Phillips and Young 1973), The control of diseases[1] such as southern blight in groundnuts, anthracnose and yellow leaf blight for maize, and bacterial blight, bacterial pustule, wildfire, anthracnose and sclerotial blight for soybeans was favoured by clean tillage. In contrast, the incidence of "take all" for small grain and Phytophthora, Rhizoctonia, Fusarium root rot, and stem rot for soybeans was greater with clean than with other tillage systems (Phillips and Young 1973). Some organisms, even when ploughed under, remain viable in soil and inoculate susceptible plants when conditions become favourable.

Some diseases can be controlled by burning crop residues (Cook et al 1978; Kronstad et al. 1978), but burning has serious adverse effects on soil and water conservation, as has been previously discussed. Control of some diseases is possible through application of chemicals and of others by developing resistant cultivars or growing susceptible crops in a rotation of sufficient length with nonsusceptible crops (Cook et al. 1978).

[1] See Appendix 5 for scientific names.

Damage from two types of animal pests, namely, rodents and sluggs, is affected by tillage systems and is usually less severe where clean rather than other tillage systems are used (Musick and Beasley 1978). For rodents, clean tillage destroys their habitat and increases their susceptibility to predators. The incidence of slugs apparently is related ton the microenvironment in the field. Slugs in the east and northeast U5A caused the most damage during warm, wet spring weather. Because clean tillage results in a generally drier condition at the soil surface than residue-based systems, slugs caused less damage to maize in clean tillage fields (Musick and Beasley 1978).

Problems from a third type of animal pest, birds, are afected by tillage method if one method results in sparser seed coverage than another. Better closing of the planter slot may occur when crops are planted after clean tillage than when planted in no-tillage wet, firm soil. Bird problems also should be lower in a clean tillage field because the soil would normally be drier (Musick and Beasley 1978), which should result in better seed coverage.

Regardless of crop produced, some type of pest problem will probably be encountered at some time during the crops life cycle. In most cases, the pest will indirectly affect soil and water conservation, usually through its effect on plant establishment, growth and yield. Some techniques for reducing damage due to pests have been discussed. Other possibilities include changing planting dates, destroying alternate-host plants, growing cultivars that mature at different times, developing hardier or more competitive cultivars and developing more effective control measures.

When pest problems occur, potential benefits from controlling or managing pests are primarily weighed against the cost of their control. Pests and their control should, however, also be considered in relation to their potential effect on soil and water conservation. No control may enhance soil and water losses whereas some control measures (for example, residue burial or burning) may also enhance soil and water losses under some conditions. Therefore, where clean tillage is used as a pest control measure, it should be used in such manner that soil and water resources will be adequately protected.

Fertilizers are usually expensive in developing countries. Therefore, crop production is mainly dependent on native or regenerated soil fertility, as in shifting cultivation systems, or on recycling of waste materials, as discussed in Section 3.2.2. When organic wastes such as various types of crop residue (leaves, stems, husks, etc.) are returned to a soil, as with clean tillage, the nutrients which they contain are in an organic form. Plants, however, absorb inorganic forms of nutrients from soils. Consequently, the nutrient elements must be converted to an inorganic form by microbial decomposition of residues. This process is termed mineralization. Tillage that incorporates organic residues with soil hastens residue decomposition and nutrient mineralization and, therefore, increases the amount of nutrients available to plants, provided the nutrients are not lost from soil through leaching or volatilization. Most rapid and greater mineralization of nutrients is obtained with clean tillage than with other forms of tillage (Black et al. 1974; Hobbs and Brown 1957, 1965; Johnson 1950; Johnson and Davis 1972; Johnson et al. 1974; Thomas in press).

Where rapid and high levels of nutrient mineralization are desirable, use of clean tillage rather than residue-conserving tillage would be an advantage. Such may be the case where high nutrient levels are desirable early in a crop's growing season so that the crop will make better use of water that is availahle mainly at that time. This could be especially beneficial for forage crops and others that develop their fruiting potential early in the growing season or that have a short growing season. For longer season crops or those that require a steady supply of nutrients throughout the growing season (Zingg and Whitfield 1957), clean tillage could be a disadvantage because initially high nutrient levels could cause luxury consumption of some nutrients early in the season (Tisdale and Nelson 1956) or losses due to leaching (Thomas in press). For these conditions, use of tillage methods that conserve residues and result in slower mineralization of nutrients would normally be more advantageous than use of clean tillage systems (Thomas in press).

Disadvantages

Disadvantages of clean tillage systems with respect to soil and water conservation result primarily from conditions at the soil surface. However, subsurface conditions, namely soil compaction and a general decline in organic matter content, are also involved. A further disadvantage of clean tillage is that it is an energy-intensive system.

Soil surface conditions, to a large extent, control water infiltration and, therefore, runoff and water erosion. For maximum infiltration, the surface must remain unsealed and receptive to water infiltration. On clean tilled soils, good infiltration is possible provided precipitation intensity is sufficiently low and soil aggregates are sufficiently stable to resist dispersion due to raindrop impact. However, as precipitation intensity increases and aggregate stability decreases, soil dispersion increases which leads to a surface roughness decrease, soil particle reorientatinn, surface sealing and restricted water infiltration into the soil (Fig. 20). In addition, the resultant dense surface layer or crust may impede soil aeration and seedling emergence (Grable 1966) and be susceptible to wind erosion. Where a crust has developed, a cultivation or other surface loosening or roughening operation may be needed to re-establish a more favourable condition.

Dispersion of clean tilled soils results primarily from raindrop impact on the bare surface. However, clean tillage also results in a general decline in soil organic matter content (Hobbs and Brown 1957, 1965; Johnson 1950; Johnson and Davis 1972; Johnson et al. 1974; Unger 1968; Unger et al 1973), which decreases aggregate stability (Johnston et al. 1943; Kemper and Koch 1966; Mazurak and Ramig 1962) and causes a general decrease in the quality of other soil physical conditions (Johnston et al 1943; Mazurak et al, 1953, 1955: Ramig and Mazurak 1964; Unger 1975a; van Bavel and Schaller 1951; Wilson and Browning 1946). Soil conditions affected include bulk density, water infiltration and permeability, water retention, compaction, porosity, and the potential for water and wind erosion.

In addition to increased soil compaction associated with decreased organic matter contents in clean tilled soils, compaction in these soils also results from raindrop impact and soil dispersion (Juo and Lal 1977), from traffic on the unprotected surface (Koshi and Fryrear 1973), and from more frequent traffic in general with clean tillage as compared with most other tillage systems.

Tillage requires energy and the total amount needed increases as the intensity and frequency of tillage increases. The energy required to perform a given operation depends on the type and size of implement, depth and speed of operation, and texture, water content and slope of soil. Mouldboard ploughing a clay soil 1.3-18 cm deep required 21.4-23.2 kW hours/ha (11.6-12.6 hp hours/acre) whereas field cultivating to the same depth required between 3.3 and 10.0 kW hours/ha (Promersberger and Pratt 1958). Ploughing the same soil 15-27 cm deep with a blade implement required 10.7-13.3 kW hours/ha.

Allen et al. (l977) reported fuel consumption values for performing various cultural operations, including some clean tillage operations, for a clay loam soil in Texas (USA) (Table 24). All results are not directly comparable because of differences in tillage depth, but the results do show that energy consumed increases with increases in intensity of tillage, as with clean tillage. The amount of energy expended for tillage has no direct influence on soil and water conservation per se. However, if energy, soil and water can be conserved by use of a particular implement or tillage system, and if other production inputs are favourable and yields are maintained at favourable levels, then use of that implement or system should be more advantageous than use of other implements or systems. In addition, it should lead to overall resource conservation and the potential for sustained crop production to supply the food needs of an ever-expanding world population.

Table 24 MEASURED AVERAGE DIESEL FUEL CONSUMP'TION FOR SPECIFIC FIELD OPERATIONS ON PULLMAN CLAY LOAM, BUSHLAND, TEXAS[1]

Operation	Tillage depth cm	Diesel fuel litres/ha
Dryland		
Sweep	8	6.1
Sweep	13	8.4
Surface-irrigated		
Mouldboard plough	20-25	28.1
Heavy tandem disk	8-13	9.4
Heavy offset disk	8-13	11.7
Lister bedder	-	6·5
Disk bedder	-	8·4
Rolling cultivator	-	5·1
Chisel, 38-cm spacing	15-20	14.0-16.8
Chisel, 50-cm spacing	15-20	12.2
Chisel, 100-cm spacing	15-20	7.5
Sweep-rodweed (bed-furrow cultivation)		7.9
Seeding		
Grain drill, 25-cm spacing		3.7

1 From Allen et al. 1977. Reprinted with permission from J. Soil and Water Conservation to use copyrighted material.

Conservation tillaqe systems

Conservation tillage systems, as used in this report, are systems for rnanaging crop residues on the soil surface with reduced or no ti1lage . The reductions may be with respect to frequency and intensity of tillage;. Some types of tillage frequently referrecd to as conservation tillage are stubble mulch tillage*, wheel-track planting, plough-plant, chisel, ecofallow, limited tillage, reduced tillage , minimum tillage*, no-tillage, zero-tillaqe, slot-plant, and direct drill. ‘The goals of these management systems are to maintain adequate plant residue on the soil surface at all times to control wind and water erosion effectively, to conserve water, and to maintain or improve crop yields. Reductions in energy, labour, amount of equipment and in its frequency of use are often additional benefits from such tillage practices.

Conservation tillage systems had their beginning in 1937 when Dr. F.L. Duley and Professor J.C. Russel conducted the first intensive research in the USA on the use of a mulch for crop production. The work was started at Lincoln, Nebraska, by the Nebraska Agricultural Experiment Station in cooperation with the Research Division of the Soil Conservation Service, US Department of Agriculture. Since that time, those and many other researchers have studied the management of crop residues on the soil surface (Unger and McCalla 1980). The system developed by Duley and Russel (1942) and subsequently improved by others is now generally known as stubble mulch tillage. The various types of conservation tillage will be discussed under the general headings of stubble mulch tillage, minimum or reduced tillage, and no-tillage.

a. Stubble mulch tillage

Stubble mulch tillage refers to tillage of soil in such a way that plant residues or other materials are maintained to cover the soil surface. Stubble mulch tillage is also referred to as mulch farming, trash farming, mulch tillage and ploughless farming (SSSA 1973).

The stubble mulch tillage and farming system was developed to combat the severe wind erosion that occurred during a major drought in the Great Plains of the United States and Canada during the 1930s. With stubble mulch tillage, residues remained anchored in the surface soil and thus trapped kept soil from erosion by wind. The surface residues were soon found to be effective also for controlling water erosion (Duley and Russel 1941, 1942; McCalla and Army 1961).

In a broad sense, any form of tillage that results in plant residues being maintained on the soil surface could be classified as stubble mulch tillage (Stallings 1957). For this report, those tillage operations that undercut surface residues to loosen soil and control weeds are considered to be stubble mulch tillage. This restriction, however, does not preclude the use of a disk-type or other implement for the first operation to incorporate some residues with soil when unusually large amounts are present (Stallings 1957; Unger and McCalla 1980). Such tillage hastens residue decomposition, but sufficient amounts are retained on the surface to control erosion. Other implements that effectively reduce large amounts of residue are stubble pulverizers and busters (Jacks et al. 1955) and mulch treaders (Fig. 82), skewtreaders, or spike-tooth harrows used in conjunction with one-way disk or sweep ploughs (Papendick and Miller 1977).

Subsurface tillage implements that maintain most residues on the soil surface include (1) sweeps - 60 cm or wider, (2) rodweeders with semi-chisels or small sweeps, (3) straight-blade machines, (4) chisel ploughs, (5) one-way ploughs (used when large amounts of residue are present), and (6) rodweeders (Unger and McCa1la 1980). Typical amounts of residue remaining on the surface after each operation with various types of implements are shown in Table 22.

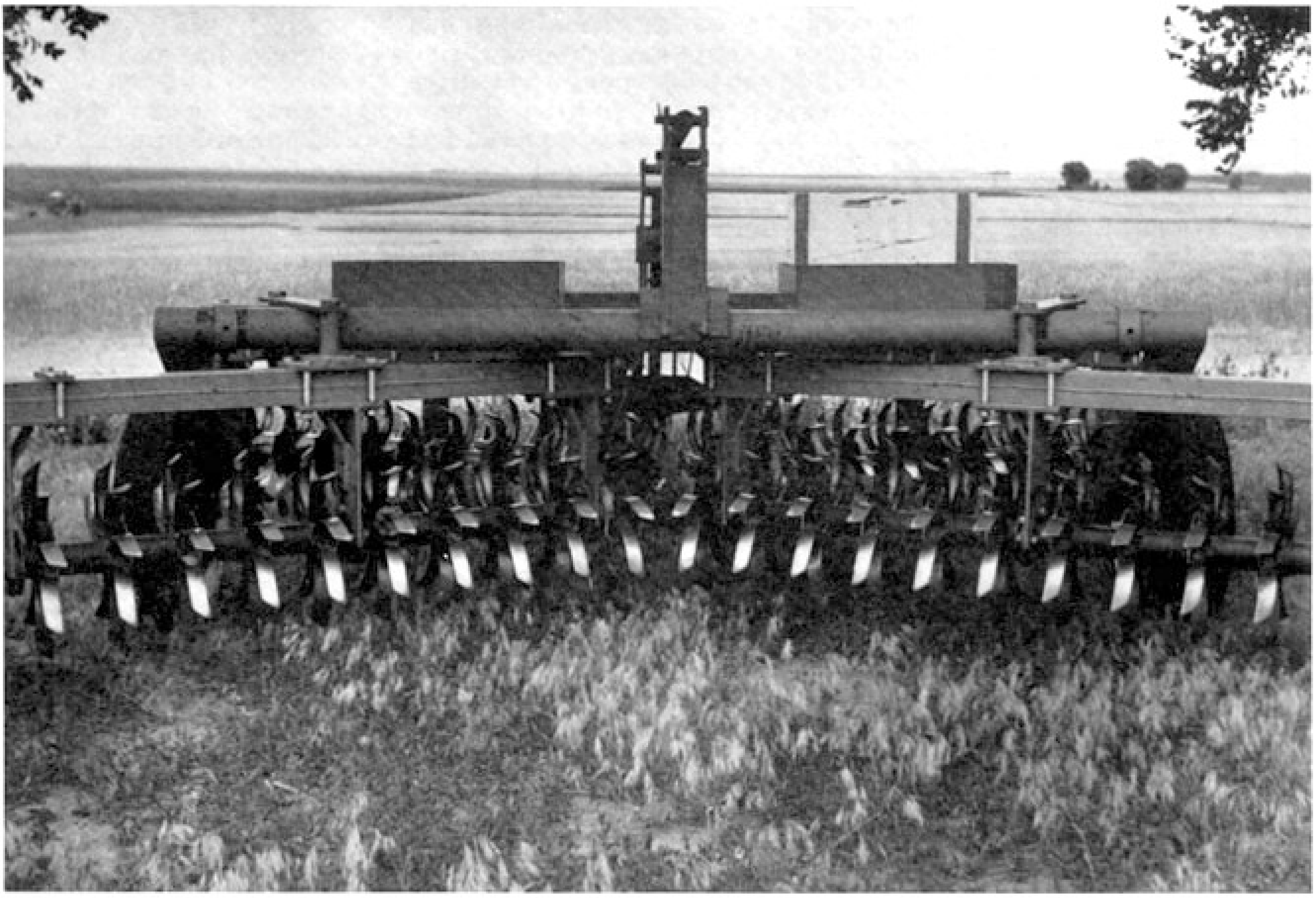


Fig. 82 Mulch treader (photo provided by C.R. Fenster, University of Nebraska)

Minimum amounts of crop residues needed to control wind erosion on various types of soil are given in Table 25. The requirements for sorghum are almost three times as large as those for wheat. This difference results from the nature of the various residues. Wheat has hollow stems and sorghum has pithy stems. Therefore a given amount of wheat straw on a weight basis provides more protection than the same amount of sorghum stubble. Other types of residue that are less effective than wheat for controlling wind erosion, in order of decreasing effectiveness, include soybeans, rape, cotton and sunflower (Lyles and Allison 1981). In addition to the effects of residue types, potential wind erosion is also affected by whether the residues are upright or flat on the surface (Lyles and Allison 1981; Skidmore and Siddoway 1978).

Stubble mulch tillage and farming is a year-round system of managing plant residues for effective control of erosion, but weed control is also important for conserving water. Therefore, tillage is performed when necessary to control weeds in the period between crops. Because frequent tillage may be required, the stubble mulch system is essentially a tillage-intensive crop production system which was developed primarily for wheat and other small grains, but is adaptable also to such crops as sorghum and maize.

Good management of stubble mulch systems begins at harvest of a crop, at which time the crop residues should be. uniformly spread to minimize subsequent tillage problems (Fig. 833). In the great Plains (USA), initial tillaqe with sweep and blade-type implements is

Table 25 APPROXIMATE AMOUNTS OF RESIDUE (kg/ha) NEEDED TO MAINTAIN EROSION BELOW A TOLERABLE LEVEL OF 11.2 TONS/HA ON VARIOUS TYPES OF SOIL[1]

Soil texture[2]	Water erosion	Wind erosion					
	Flattened wheat residue	Wheat residue		Growing wheat		Sorghum residue	
		Standing	Flattened	Standing	Flattened	Standing	Flattened
Silts	1 600	500	1 000	560	480	2 000	2 900
Clays and silty loams	2 100	900	1 800	1 100	930	3 700	5 300
Loamy fine sands	1 000	1 200	2 400	1 300	1 000	4 700	6 900

1 From Anderson 1968; Fenster 1973. Reprinted with permission from J. Soil and Water Conservation to use copyrighted material.

2 Silts with 50 percent nonerodible fractions greater than 0.84 mm in diameter. Clay and silty clay with 25 percent and loamy sand with 10 percent nonerodible fractions.

Fig. 83 Harvester equipped with straw spreading attachment: spreading the straw minimizes subsequent tillage problems

generally 12 to 15 cm deep. Subsequent tillage is at successively shallower depths. In dry-farming areas of the Pacific Northwest (USA) and at more humid locations where residue production by small grains is generally much higher than in the Great Plains, initial tillage depth is similar othat in the Great Plains. The next operation, however, may be deeper to avoid serious clogging. In each region, subsequent operations are usually at progressively shallower depths to provide a firm, well-preparecd seedbed for planting the next crop (Hanway 1970).

Stubble mulch tillage is adaptable to all types of soils. However, coarse-textured soils require more surface residues to control wind erosion than fine-textured soils (Fenster 1973; Hanway 1970; McCalla and Army 1961; also, Table 25). Wind erosion would, therefore, be more easily controlled with stubble mulch tillage on fine-textured than on coarse-textured soils. In addition, where inadequate residues are present, a rough, cloddy surface can usually be produced more easily on a fine-textured than on a coarse-textured soil, thus providing additional protection against wind erosion in emergency situations.

Soil erosion by water should be more easily controlled by stubble mulch tillage and other conservation tillage systems on coarse than on fine-textured soils because water infiltration is usually more rapid into coarse than into fine-textured soils. Consequently, less surface residues would be required on coarse-textured soils to keep water erosion to less than 11.2 tons/ha (5 tons/acre). The approximate amounts of grain residue needed to keep water erosion below the tolerable level are included in Table 25, and are adapted from Anderson (1968).

The stubble mulch system is better adapted to arid and semi-arid climatic regions than to subhumid and humid regions, based on the ratio of wheat yields from stubble mulch and clean tillage areas at several locations in western USA (Zingg and Whitfield 1957). The increased yields with stubble mulch tillage at the drier locations appear to be related to lower nitrification which prevents over-stimulation of plant growth and, in combination with improved water infiltration, improves the water-fertility balance (Johnson 1950; Zingg and Whitfield 1957). Undoubtedly, improved weed control at the drier locations is a factor also.

In the part of the Great Plains (USA) where yield increases occurred with stubble mulch tillage, water rather than fertility is normally the factor that limits plant growth and yield. Therefore, lower nitrification early in the growing season when more water is sometimes available depresses plant growth and thereby more soil water remains for sustaining the plant through the period of grain production (Zingg and Whitfield 1957). At more humid locations where fertility rather than water is the limiting factor, lower nitrification with stubble mulch tillage results in lower yields. The response to applied N was greater with stubble mulch tillage than with mouldboard ploughing at a subhumid location (Zingg and Whitfield 1957).

In addition to the improved water-fertility balance at drier locations (Johnson 1950; Zingg and Whitfield 1957), increased soil water contents per se at the drier locations also contributed to higher yields with stubble mulch tillage. At more humid locations, water is less often a yield-limiting factor.

Data in Tables 26, 27 and 28 illustrate the water conservation benefits resulting from use of stubble mulch tillage at several western USA locations. At Bushland, Texas, ,Johnson and Davis (1972) evaluated the effects of tillage method on soil water contents and grain yields for winter wheat in continuous and fallow systems (Table 26). Stubble mulch tillage (subtillage) resulted in higher water contents at seeding and higher grain yields in both cropping systems. A delayed subtillage treatment for which the land was not ploughed from wheat harvest (usually in June) until weed growth began the next spring (usually in May) also resulted in higher water contents and yields than the one-way tillage treatment, and only slightly lower water contents and yields than the other subtillage treatment.

Table 26 CROPPING SYSTEM AND TILLAGE EFFECTS ON AVERAGE PLAN'T AVAIILABLE SOIL WATER TO A DEPTH OF 1.8 m, GAIN IN SOIL WATER, PRECIPITATION DURING FALLOW AND WHEAT YIELDS AT BUSHLAND, TEXA.S (USA), 1958 TO 1969
(from Johnson and Davis 1972)

Cropping system and tillage method	Seasons of data	Plant available water		Gain in water		Fallow precipi-tation	Grain yield
		At harvest	At seeding				
	No.	cm	cm	cm	%[1]	cm	kg/ha
Continuous wheat '							
One-way disk	11	5.1	9.2	4.1	20	20.1	650
Subtillage	11	6.1	10.6	4.5	22	20.1	760
Wheat-fallow[2]							
One-way disk	10	6.1	12.5	6.4	9	67.5	1 000
Subtillage	10	5.8	16.1	10.3	15	67.5	1 050
Delayed subtillage	10	5.2	13.9	8.7	13	67.5	1 030

1 Percent of precipitation.

2 One crop in 2 years.

The generally favourable results with delayed subtillage occurred even though weeds on those plots used a large amount of soil water from wheat harvest until frost. However, by seeding time the next autumn, sufficient water was usually stored so that yields were similar to those on other subtillage plots. In addition, delayed subtillage required about 30 percent fewer tillage operations than regular subtillage. Delayed subtillage, therefore, has been recommended for winter wheat production (Bond et al. 1961; Smika 1976), but is seldom used because large amounts of weed seeds are produced in some years (Johnson and Davis 1972). Where residue production by crops is low, the additional plant material produced by weeds could aid wind erosion control if the materials are managed through use of delayed subtillage and if favourable crop yields are maintained.

Smika (1976) summarized the effects of tillage methods on the gain in soil water during fallow at several Great Plains (USA) locations. The average increase with stubble mulch tillage as compared to clean tillage was 2.7 cm with increases at different locations ranging from 0.3 to 5.7 cm (Table 27). For the same locations and years (excluding 2 years at Akron, Colorado), wheat grain yields averages 1950 and 2130 kg/ha with clean and stubble mulch tillage, respectively.

Table 27 NET GAIN IN SOIL WATER DURING FALLOW WITH CLEAN AND STUBBLE MULCH TILLAGE AT SEVEN CENTRAL GREAT PLAINS LOCATIONS (USA) (from Smika 1976)

Location	Years of data No.	Tillage method: Clean cm	Stubble mulch cm
Akron, Colorado	6	14.2	17.3
Colby, Kansas	4	11.5	14.1
Garden City, Kansas	6	8.6	9.0
Oakley, Kansas	4	8.2	13.1
North Platte, Nebraska	8	14.6	20.3
Alliance, Nebraska	8	2.9	3.2
Archer, Wyoming	2	2.8	4.2
Weighted average		9.5	12.2

Greb (1979) evaluated the effect of changes in tillage methods on soil water storage during fallow and on wheat yields at Akron, Colorado (USA), for different periods beginning in 1916. The results (Table 28) illustrate the advantages of maintaining surface residues by conservation tillage methods for conserving water and increasing crop yields. While increased water conservation undoubtedly was a

Table 28 EFFECT OF CHANGES IN TILLAGE METHODS DURING FALLOW ON SOIL WATER STORAGE AND WHEAT YIELDS AT AKRON, COLORADO (USA), 1916 TO 1990 (PROJECTED) (from Greb 1979)

Years	Tillage methods	Average annual precipi-tation cm	Drought years No.	Water stored cm	Fallow effi-ciency[1] %	Wheat yield kg/ha	Water use effic-iency[2] kg/ha-cm
1916-30	Maximum tillage - plough, harrow (dust mulch)	43.9	1	10.2	19	1 070	12
1931-45	Conventional tillage - shallow disk, rodweeder	40.1	5	11.2	24	1 160	14
1946-60	Improved conventional tillage; begin stubble mulch (1957)	41.7	3	13.7	27	1 730	21
1961-75	Stubble mulch; begin minimum tillage with herbicides (1969)	38.9	4	15.7	33	2 160	28
1976-90	Minimum tillage; begin no-tillage (1983) (projected)[3]	41.1	3	18.3	40	2 690	33

1 Based on precipitation during 14 months of fallow (mid-July to second mid-September).

2 Assuming 2 years precipitation per crop in a wheat-fallow system.

3 Assuming average precipitation from 1976 to 1990.

Fig. 84 Surface residues on stubble mulch tillage field provide protection against erosion by wind and water (USDA-Soil Conservation Service photo)

Table 29 EFFECT OF TWO TILLAGE SEQUENCES COMMONLY USED IN A WHEAT-FALLOW SYSTEM ON AMOUNT OF RESIDUE CONSERVED, SOIL CLODDINESS, AND POTENTIAL SOIL EROSION BY WIND
(from Woodruff 1972)

Tillage sequence		Residue remaining after operation		Clods >0.84 mm in diameter	Potential soil loss[1]
Operation No.	Machine	%	kg/ha	%	tons/ha
0	Pretillage	100	2 240	-[2]	-[2]
1	2.4 m V-sweep	86	1 930	65	0.2
2	0.8 m sweep	74	1 660	60	1.0
3	Rodweeder	63	1 410	58	2.0
4	Rodweeder	53	1 200	57	8.3
0	Pretillage	100	2 240	-	-
1	One-way	57	1 280	71	0,9
2	One-way	40	900	67	7.2
3	0.8 m sweep	44	990	66	6.2
4	Rodweeder	37	840	64	10.1

1 Potential soil loss computed with the wind erosion equation (Woodruff and Siddoway 1965) using indicated cloddiness and residue levels with C′ (climatic factor) of 100, K′ (roughness factor) of 1.0, and L′ (field length) of 805 m (2640 feet).

2 Nonerodible.

major contributor, the yield increases per unit increase in Stored water were greater than predicted by Johnson (1964). Other factors probably contributing to the yield increases were improved varieties, weed control and soil fertility, as well as better use of growing season precipitation (Unger 1982c).

Weed control is not usually a problem with stubble mulch tillage at the drier locations in the Great Plains (USA) (Zingg and Whitfield 1957), but may be difficult during unusually wet periods or when rainfall occurs soon after tillage. In the latter case, stubble mulch tillage severs weed roots, but there may be regrowth if rainfall occurs before the weed is killed (Hanway 1970). Use of treaders (Fig. 82) in conjunction with stubble mulch implements impro1ves weed control, especially when the soil is relatively dry at the time of tillage (Hanway 1970; Zingg and Whitfield 1957).

At more humid locations where rainfall is more frequent, greater difficulty is usually encountered in controlling weeds with stubble mulch than with clean tillage. The most difficult weeds to control with stubble mulch tillage in wheat in the Great Plains and Northwest USA are cheatgrass[1] and downy brome. Use of treaders improved control of these weeds (Zingg and Whitfield 1957). Other control methods include herbicides, the inclusion of sorghum in rotation with wheat, and the occasional use of clean tillage (Hanway 1970). Other weeds undoubtedly would be troublesome for other crops under other environmental conditions.

The value of surface residues to control soil erosion, both by wind and water, is widely recognized and has been discussed previously (Fig. 84). For both types of erosion, the degree of control increases with increasing amounts of residue on the surface. Because stubble mulch tillage retains residues on the surface, it is an effective erosion control practice and has become the basic tillage method in a number of dryland farming regions where there is a threat of wind erosion in many years (Unger and McCalla 1980). An example of tillage effects on potential wind erosion is given in Table 29 (Woodruff 1972).

Without adequate surface residues, stubble mulch tillage (subtillage) may not control wind erosion, and would be less effective than chisel, lister or other tillage methods that result in a rough, cloddy or ridged surface. In fact, Unger (1982b) showed that the surface layer of Pullman clay loam in Texas had more aggregates in the wind-erodible range (< 0.84 mm diameter) with a stubble mulch tillage than with clean (one-way disk) tillage.

As for control of wind erosion, control of water erosion is apparently little affected by tillage method per se, but is highly dependent on the amount of residues retained on the surface by different tillage methods. Relatively small amounts of surface residue are effective for controlling water erosion (Table 25). For example, 2.2 tons/ha of surface residues with stubble mulch tillage resulted in 2.8 and 8.1 tons/ha of soil loss annually in a maize-oats-wheat cropping system at Lincoln, Nebraska, and in a wheat-fallow system at Pullman, Washington, respectively. With mouldboard ploughing, the respective losses were 13.4 and 40.2 tons/ha annually (Zingg and Whitfield 1957).

[1] Scientific names for weeds are given in Appendix 6.

Allmaras et al. (1980) showed no reduction in soi1 loss with sweep (stubble mulch) tillage as compared to mouldboard ploughing in a wheat-fallow system when about 0.1 tn/ha of residue was on the surface at planting time. With increasing amounts of residue (0.4, 0.8 and 2.0 tns/ha), weighted average Soil losses with stubble mulch tillage were about 82, 54 and 28 percent, respectively, of those occurring with mouldboard ploughing. Although actual soil losses differed, the percentage reductions in soil losses were relatively constant with increasing amounts of surface residues, regardless of soil slope, slope length and tillage direction (on the contour or not related to contour).

When land is put into cultivated crop production, soil organic matter content decreases rapidly at first and, thereafter, at a declining rate with time (Johnson and Davis 1972). Associated with the decline in organic matter are lower water infiltration, decreased aggregate stability and porosity, and increased density and compaction. Clean tillage is especially harmful with respect to maintaining high soil organic matter contents (Section 3.2.4.ii.e). Compared with clean tillage, the rate of organic matter decline is lower with stubble mulch tillage, and especially with delayed stubble mulch tillage. Pullman clay loam in Texas contained 2.44 percent organic matter in the surface 15 cm of soil in 1941. In 1977, it contained 1.71 and 2.09 percent where one-way disk and stubble mulch tillage, respectively, were used for annual production of winter wheat during the 36-year period. In wheat-fallow plots, the soil contained 1.62, 1.79 and 2.28 percent organic matter where one-way disk, stubble mulch and delayed stubble mulch tillage were used (Unger 1982b). The values in 1977 were not greatly different from values obtained in 1966 (Unger 1968), indicating that the soil organic matter content was in or approaching an equilibrium level compatible with prevailing crop management and environmental conditions. Because soil N content is closely related to organic matter content (Unger 1968), maintaining organic matter contents at relatively high levels is important for maintaing soil fertility, especially in countries where no or limited amounts of fertilizers are applied.

The stubble mulch tillage system was developed primarily for use in semi-arid to arid regions. In those regions, tillage and planting can usually be achieved without difficulty with suitable equipment. However, in occasional years when residue production is much above normal and in more humid regions where residue production is normally high, difficulties may be encountered in performing the necessary operations. Under such conditions, one-way disks, tandem disks, offset disks, stubble pulverizers or busters, skewtreaders, or spike-tooth harrows (Jacks et al. 1955; Papendick and Miller 1977; Stallings 1957; Unger and McCalla 1980) can be used for initial operations to reduce the amount of surface residues. However, these implements should be used with caution and in such a manner or frequency as to assure that sufficient residues are maintained throughout the non-cropped period and at planting time to provide adequate protection against wind and water erosion (Table 26).

In addition to difficulties in performing tillage when large amounts of residue are present in a stubble mulch system, the tillage is often less effective for controlling weeds than under drier, lower residue conditions. Weed control is more difficult because high amounts of residue are conducive to higher soil water contents. Therefore, tillage may need to be delayed to await a lower soil water content or else the weeds may not be destroyed by tillage because some roots may remain in moist soil, even thouqh most weed roots are severed by the subsurface tillage. A treader used in conjunction with a stubble mulch implement when the surface soil is dry improves weed control. In addition, it is important that the implements be properly adjusted and operated at the proper speed and depth to achieve effective weed control (Hanway 1970). Where weeds are not satisfactorily controlled, yields usually decrease with stubble mulch tillage. For example, Bond et al. (1971) obtained spring wheat yields of only 1060 kg/ha with stubble mulch tillage whereas the average yield for three treatments involving mouldboard ploughing was 1360 kg/ha. The yield reduction with stubble mulch tillage was attributed to poor weed control, primarily of green foxtail.

In recent years, herbicides have been widely used, either to replace tillage or to assist tillage in controlling weeds. When used in conjunction with stubble mulch tillage in wheat-fallow or wheat-fallow-sorghum cropping systems, substantial increases in soil water contents and grain yields have been obtained by applying herbicides (Phillips 1969; Smika and Wicks 1968; Wicks and Smika 1973). To be effective, however, the herbicides must cover the soil uniformly. Large amounts of surface residue could result in non-uniform herbicide application and, therefore, result in poor weed control (Richey et al. 1977). Interception of herbicides by residues may have reduced the effectiveness of some treatments for controlling weeds in the studies by Phillips (1969) and Wicks and Smika (1973). However, Unger et al.(1971) and Unger and Wiese(1979) obtained complete weed and volunteer wheat control when atrazine was applied to areas having up to 11 tons/ha of standing wheat residue on the surface.

A problem sometimes encountered with stubble mulch and other conservation tillage systems is the toxic effect of substances from residues on subsequent crops. This problem, known as phytotoxicity or allelopathy (Elliott et al. 1978), was recognized soon after mulch tillage studies were initiated (McCalla and Army 1961) and is seemingly most severe when subsequent crops are planted with large amounts of residue present on the soil surface.

Yield reductions with stubble mulch tillage in subhumid and humid locations may have been related to toxic substances released by decaying residues (Elliott et al. 1978). However, there are also numerous reports which show that yields of crops planted into large amounts of residue are not adversely affected, even at humid locations.

Phytotoxicity may be related to residue type, crop grown, soil environment and other factors. Where phytotoxicity is a known or suspected problem, adverse effects can be minimized by keeping residues as far as possible from the seed row and by harvesting them where practical (Elliott et al. 1978). However, sufficient residues should be maintained on the soil surface for effective soil and water conservation where these factors are important.

b. Minimum or reduced tillage

Controlling weeds is a major reason for tilling a soil. Therefore, if weeds can be controlled by another means, the need for tillage is

[1] See Appendix 6 for scientific names.

reduced and such an alternate is to use herbicides. The development in recent years of a wide array of herbicides effective for controlling many types of weeds in numerous crops has permitted the development of various minimum or reduced tillage systems. In these systems, herbicides are usually relied on to provide weed control during at least a part of the crop production cycle. However, in contrast to the no-tillage system, which is discussed in the next section, most or all of the soil surface is disturbed one or more times by tillage for seedbed preparation and by the planting operation.

As with stubble mulch tillage, major goals of minimum and reduced tillage systems are soil and water conservation, which are achieved by retaining crop residues on the surface as long as possible, especially during major erosive periods. The land may be mouldboard ploughed in some cases, but the number of secondary tillage operations is greatly reduced.

Minimum or reduced tillage studies, begun in New York in the early 1940s, were the first or among the first such studies conducted in the USA. In these early studies, disking or a modified form of ploughing was substituted for mouldboard ploughing, but maize yields were lower than with conventional seedbed preparation because disking in early spring compacted the soil (Bennett 1977).

A system that combined turn-ploughing and planting in one operation was developed for maize in 1956. Maize yields compared favourably with those for conventional practices, and soil erosion was one-sixth of that with conventional tillage. This and further research indicated that any tillage beyond a minimum needed to obtain a good seedbed was wasteful and often reduced maize yields (Bennett 1977).

As a consequence of the promising results in the early studies and the development of suitable herbicides to control weeds in many situations, further development of minimum and reduced tillage systems expanded rapidly during the 1960s in the USA. Research on these systems was conducted at numerous locations and the results are summarized in reports by Amemiya (1977), Fisher and Lane (1973), Griffith et al.(1977), Oschwald (1973), Phillips et al.(1976), and Reicosky et al. (1977). Brief descriptions of the major minimum or reduced tillage systems are given in the following paragraphs.

Fall (autumn) plough, field cultivate. In this system, primary tillage is with the mouldboard plough and secondary tillage is reduced to one shallow cultivation with sweeps at planting. A disk or rotary tiller may be used instead of the field cultivator to produce a finer, firmer seedbed, but this creates a more erodible soil conditions. The fall (autumn) plough, field cultivate system is widely used on the dark, nearly level, medium to fine-textured clay loam soils of the east central Corn Belt (USA).

Spring plough, wheel-track plant. This system used strip seedbed preparation on soil that was initially ploughed only 12 to 24 hours before planting the crop. By planting soon after ploughing, the soil does not dry appreciably and the soil water content at planting is such that the wheels break the clods and make firm the seedbed. Seedbed preparation and planting are accomplished in the same operation. The planted rows may be in the tractor or planter wheel tracks. This system provides greater protection against erosion than fall ploughing because residues from the previous crop are maintained on the surface until ploughing.

Fall (autumn) chisel, field cultivate. This system is similar to the previous, except that mouldboard ploughing is replaced by chiselling 20-25 cm deep. Because this latter retains more surface residues than the former, the system more effectively cnntrnls ernsinn than the previous one. Some variations of chisel systems are given in Table 30, which is adapted from Oschwald (1973).

Table 30 TILLAGE OPERATIONS INCLUDED IN FOUR TYPFS OF CHISEL PLOUGH SYSTEMS[1]

Type of system	Primary tillage	Secondary tillage	Planting
Chisel-plant	Fall chisel (straight or twisted points)[2]	None	Chisel-plant (1 pass) (chisel plough with 40-cm Sweeps on 38-cm centres). Planter modified to plant in heavy residues
Chisel-secondary tillage	Fall chisel (straight or twisted points)	a. Disk + harrow or b. Field cultivate + harrow	Planter modified to plant in heavy residues
Combination Coulter or Disk-chisel	a. Fall coulter-chisel or b. Fall disk-chisel (straight or twisted chisels in (a) and (b))	a. Disk-chisel (sweeps) or b. Disk + harrow or c. Field cultivate + harrow	Planter modified to plant in heavy residues
Alternate Chisel-Mouldboard plough	a. Following soybeans - fall chisel (straight or twisted points) b. Following maize - fall mouldboard plough	a. Field cultivate + harrow or b. Disk + harrow	Conventional planter

1 From Oschwald 1973. Reprinted with permission from J. Soil and Water Conservation to use copyrighted material.

2 Fall = autumn

Disk and plant. Tillage in this system is accomplished with tandem disks operated 8-10 cm deep, heavy disks operated 15-20 cm deep, or a combination of the two. The initial disking is usually in the autumn followed by one or more diskings in spring before planting. To conserve surface residues, disking should be delayed as long as possible, and tandem rather than heavy disks should be used because the former do not penetrate as deeply or incorporate as much residue as the latter.

Till-plant. Several types of till-plant systems have been developed in which tillage and planting are or can be accomplished in one operation. In the system developed in Nebraska (USA), tillage is with wide sweeps operated 5-8 cm deep on the ridge remaining from the previous crop. This tillage moves old stalks and root clumps into the zone between rows and provides a trash-free zone for planting. The ridges were formed during cultivation of the previous crop or after harvest with rolling or disk-hiller cultivators, large disk cultivators, or disk bedders (Fig. 85). In cases where heavy disks are used to cut residues and level old ridges, ridges must be re-formed annually. Where ridges are maintained from year to year, the only tillage required is for reshaping ridges in the autumn or spring with a rolling or disk-type cultivator.

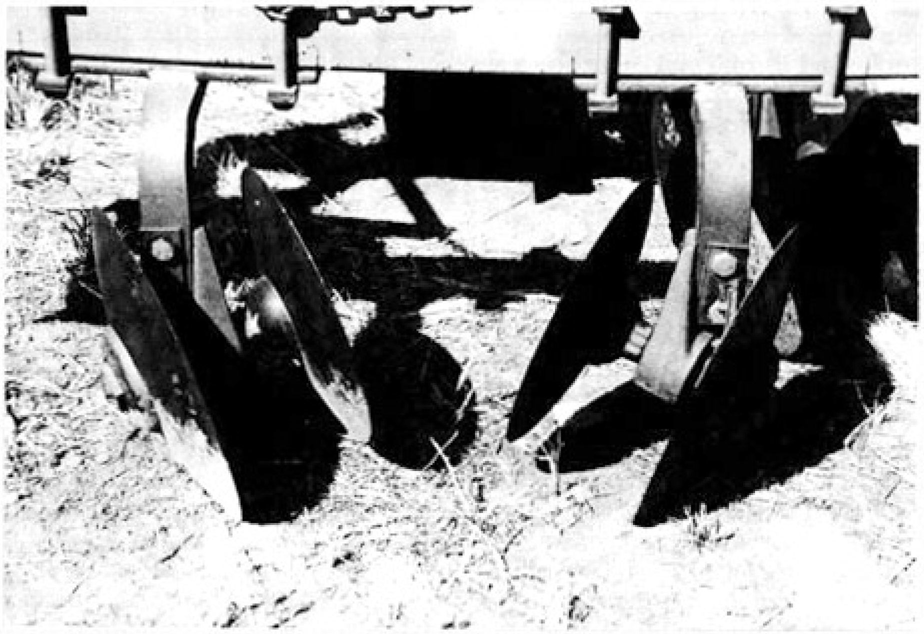


Fig. 85 Disk bedder showing disks for one bed

A variation of the above system involves alternating the position of the row and inter-row zone from year to year. In this system, a ridge is initially formed between the rows at planting and at subsequent plantings, this ridge is split and becomes the planted row. During the splitting and planting operation, residues and remaining stalks are buried in the new ridge formed between the rows. These residues decay during the growing season and help provide a favourable seedbed for the next crop.

Two types of implements have been developed for use on soils in the southeastern USA that have compacted subsurface layers. With these implements, the compacted soil is loosened and the crop is planted directly over the loosened zone. One implement is the “ripper-hipper”, which subsoils the compacted layer under the intended row zone and forms a ridge over the slit with hillers or bedders. The crop can be planted in the same operation. The other implement is the subsoiler-planter, which loosens the compacted layer, firms loose soil in the slits with treading wheels, and plants the crop with unit planters, all in one operation. Both implements can be equipped with coulters to cut surface residues.

Strip tillage. Only a narrow band of soil is tilled in a strip tillage system. Rotary tillers can be adapted for strip tillage by removing some of the blades. A typical tillage zone is about 20 cm wide and 5-10 cm deep. By attaching a standard planter to the tiller, tillage and planting can be accomplished in one operation because residues from previous crops are chopped by the tiller.

Tillage-herbicide combinations. Use of herbicides for weed control between crops reduces the need for frequent tillage and, therefore permits more crop residues to be maintained on the surface for controlling erosion. Tillage-herbicide combinations have received considerable attention where residue production is low, erosion potential is high, water conservation is important for good crop production, and troublesome weeds cannot be effectively controlled either by tillage or herbicides alone. Although variations of these systems exist, common practices are: (1) to use tillage initially to control existing weeds, loosen the soil, or incorporate some residues, and then apply herbicides for subsequent weed control; (2) to apply herbicides initially so that tillage can be delayed to maintain more residues on the surface during erosive periods, then use tillage as planting time approaches to prepare a seedbed; and (3) to use tillage for one crop and herbicides for the other in two-crop rotations. Tillage-herbicide combinations have proven successful for controlling erosion, conserving water, and increasing crop yields, especially at locations where precipitation is limited (Papendick and Miller 1977; Phillips 1969; Smika and Wicks 1968).

Other systems. Other minimum or reduced tillage systems that can maintain residues on the surface during at least a major part of the crop production cycle include: lister plough, plant; rotary till, plant; and sweep plough, plant. These and possibly some others are essentially variations of the previously discussed systems and differ mainly with respect to type of implement used. Choice of system must consider the equipment available, soil and climatic conditions, crop to be grown, size and type of farming operation, and the producer's managerial ability and personal preferences (Griffith et al. 1977).

Many studies involving various minimum or reduced tillage methods or systems have been conducted at numerous locations in the USA. Soil and water losses were measured in some studies while in others only soil water contents, or crop yields were determined. Results from some minimum and reduced tillage studies have been shown in Tables 4, 10, 19, and 28. Some further examples are discussed in the following paragraphs.

Studies in Indiana and Illinois with simulated rainfall on a 9 percent sloping soil showed the effectiveness of chisel, till-plant and no-tillage systems for reducing runoff and soil losses compared to a plough-disk-plant system (Table 31). The chisel, till-plant and no-tillage systems reduced soil losses 94, 60 and 85 percent during 2 hours of high intensity rain. The chisel system resulted in the greatest runoff reduction followed by the no-tillage and till-plant systems. The trends were in the same order for soil losses (Griffith et al. 1977).

In Illinois (USA) on Catlin silt loam with 5 percent slope, disk-chisel and no-tillage reduced soil losses 89 and 91 percent respectively after maize, and 71 and 85 percent, respectively, after soybeans as compared to mouldboard ploughing in the autumn (Table 32). Under the simulated rainstorms, soil losses were substantially higher after soybeans than after maize, which emphasizes the major effect of surface residues and previous crop on soil loss. Soybeans produce much less residue than maize; therefore, soil losses are of major concern after soybeans in the eastern Corn Belt (USA) where an alternate maize-soybean system is widely used (Griffith et al. 1977).

Table 31 RUNOFF AND SOIL LOSS FROM BEDFORD SILT LOAM (9 PERCENT SLOPE) DURING ONE-HOUR ARTIFICIAL RAINSTORMS, 1972 [1] [2]

Tillage system	Runoff		Soil loss	
	1st hour	2nd hour	1st hour	2nd hour
	cm		tons/ha	
Spring plough, disk, plant	4.5	5.6	23.3	27.1
Spring chisel, field cultivate, plant	1.1	3.8	0.7	2.5
Till-plant	3.7	5.0	7.4	8.5
No-tillage	2.6	3.9	3.6	3.8

[1] Storms of 6,5 cm/hour were applied within 4 weeks after planting maize in rows that ran across the slope. Data are averages of two replications.

[2] From Griffith et al. 1977. Reprinted with permission from J. Soil and Water Conservation to use copyrighted material.

Table 32 RUNOFF AND SOIL LOSS AS INFLUENCED BY WATER APPLIED[1], TIME OF APPLICATION, TYPE OF FALL TILLAGE AND PREVIOUS CROP[2]

Time[3] minutes	Water applied cm	Fall mouldboard plough Maize	Fall mouldboard plough Soybean	Disk-chisel Maize	Disk-chisel Soybean	No fall tillage Maize	No fall tillage Soybean
			Runoff - cm				
60	6.4	3.0	3.9	0.1	2.1	2.3	3.2
90	9.5	5.8	6.9	0.8	5.1	4.6	6.0
120	12.7	8.6	9.6	2.9	8.3	7.1	8.8
			Soil loss - tons/ha				
60	6.4	4.2	10.9	0.06	2.8	0.4	1.4
90	9.5	8.6	18.0	0.4	5.2	0.8	2.6
120	12.7	12.7	25.6	1.4	7.5	1.1	3.9

[1] Simulated rainfall was applied at a rate of 6.5 cm/hour after over-winter soil weathering, but before any spring tillage.

[2] From Griffith et al. 1977. Reprinted with permission from J. Soil and Water Conservation to use copyrighted material.

[3] Cumulative time from start of water application.

Average maize yields obtained over a 7-year period on four soils in Indiana are shown in Table 33. The soils differed in texture, drainage and organic matter content. In northern Indiana, yields with reduced tillage were as good as with the plough system, except on the poorly drained Runnymede loam on which yields with no-tillage were lower. Yields with no-tillage were also much lower in east central Indiana, again on a poorly-drained soil. At this location, yields with chisel and till-plant systems were also somewhat lower than with the plough system. On the sloping soil at the southern location, lowest yields were obtained with the plough system (Griffith et al. 1977).

Table 33 MAIZE YIELD RESPONSE TO TILLAGE SYSTEMS IN INDIANA, (USA), 1967-73

Tillage system	Northern Indiana		East Central Indiana	Southern Indiana
	Tracy Sandy loam	Runnymede loam	Blount silt loam	Bedford silt loam
	- kg/ha -			
Spring plough, disk twice, plant	7 650	8 400	7 460	5 830
Fall chisel, field cultivate, plant	7 840	8 150	6 710	6 400
Till-plant in last year's ridges	8 660 [2]	8 340	6 650	6 710 [2]
Coulter plant (no-tillage)	7 780	7 210	4 890	6 270

[1] From Griffith et al. 1977. Reprinted with permission from J. Soil and Water Conservation to use copyrighted material.

[2] Cultivation to form ridges may have improved yield on these low organic matter soils. Crops were not cultivated in the other systems.

A wider array of tillage systems was evaluated with respect to maize yields in a 3-year study on two soils in Illinois (Griffith et al. 1977). On the somewhat poorly drained Flanagan silt loam, fall ploughing resulted in slightly higher yields than other systems (Table 34). Yields with chop-plant (no-tillage) were lower than with other systems on the moderately well-drained Catlin silt loam. Reasons for lower yields with no-tillage on this soil are not apparent because they are usually better with no-tillage, except on poorly drained soils (Triplett et al. 1970).

Table 34 MAIZE YIELD RESPONSE TO TILLAGE SYSTEMS IN ILLINOIS, (USA), 1973-75 [1]

Tillage system	Flanagan silt loam kg/ha	Catlin silt loam kg/ha
Fall plough	9 780	9 660
Disk-chisel	9 220	9 410
Coulter-chisel	9 220	9 280
Chisel	9 220	9 600
Chop-plant (no tillage)	9 090	8 530
Disk	8 840	9 220
Spring plough	8 340	-

1 From Griffith et al.1977. Reprinted with permission from J. Soil and Water Conservation to use copyrighted material.

Table 35 MAIZE AND SOYBEAN YIELDS AS INFLUENCED BY TILLAGE SYSTEMS IN NORTHWEST IOWA (USA), 1968-75 [1]

Tillage system	Continuous maize	Maize after so beans	Soybeans after maize
	kg/ha		
Mouldboard plough, disk twice, harrow, plant	5 960	6 520	2 130
Mouldboard plough, field cultivate, plant	6 080	6 710	2 200
Till-plant	6 150	6 590	2 130
Lister plough	6 080	6 900	2 010

1 From Amemiya 1977. Reprinted with permission from J. Soil and Water Conservation to use copyrighted material.

Table 36 MAIZE AND SOYBEAN YIELDS AS INFLUENCED BY TILLAGE SYSTEMS AT WASECA, MINNESOTA (USA) [1]

Tillage: Fall	Tillage: Spring	Maize after soybeans 1974-75	Soybeans after maize 1973-75	Maize after maize 1975
		kg/ha		
Mouldboard plough	Field cultivate	7 280	2 700	6 150
Chisel plough	Field cultivate	7 150	2 700	4 330
None	Mouldboard plough, disk, field cultivate	6 650	2 630	-
None	Chisel, disk	7 150	2 700	-
None	Disk twice	7 780	2 700	-
None	Till-plant (ridge)	-	-	6 590
None	Till-plant (flat)	-	-	6 960
None	Slot plant (no-tillage)	6 270	2 380	4 580

1 From Amemiya 1977. Reprinted with permission from J. Soil and Water Conservation to use copyrighted material.

Table 37 MAIZE YIELDS AS INFLUENCED BY TILLAGE SYSTEMS AT LINCOLN, NEBRASKA (USA), 1972-75 [1]

Tillage: Fall	Tillage: Spring	Yield kg/ha
Chop stalks, disk, mouldboard plough	Disk, plant	4 920
Chop stalks, chisel plough	Disk, plant	5 080
Chop stalks, sweep plough	Disk, till-plant	5 050
Disk, chisel plough	Disk, chisel with sweeps, plant	5 040
Coulter-chisel	Disk, plant	5 390
Chop stalks	Till-plant	5 380
Chop stalks	Slot plant (no-tillage)	5 220

1 From Amemiya 1977. Reprinted with permission from J. Soil and Water Conservation to use copyrighted material.

Amemiya (1977) reported results from several states (USA) regarding the effects of tillage systems on crop yields. In Iowa, tillage system had no significant effect on maize or soybean yields (Table 35). Some differences due to tillage method were found in Minnesota, but yields with some reduced tillage systems were better than with mouldboard ploughing (Table 36). Possible reasons for yield reductions with some systems, especially slot planting (no-tillage) were lower soil temperature in spring; weed, insect, and disease problems; poor seed placement; and lower nutrient availability (Amemiya 1977). In Nebraska, yields with all conservation tillage systems were as good or better than with mouldboard ploughing (Table 37).

Water conservation and wind erosion control are major goals for tillage systems in the western part of the USA (Great Plains region), where tillage-herbicide combinations have been shown to be effective for conserving water, controlling erosion, and increasing crop yields, mainly because of increased amounts of residues maintained on the soil surface by use of these systems. For sorghum in a wheat-fallow-sorghum rotation in Kansas, grain yields were significantly higher with three tillage-herbicide combinations than with either conventional tillage or no-tillage, which resulted in similar yields (Table 38). The yield increases probably resulted from increased soil water contents because weed control was similar with conventional tillage and all tillage-herbicide combination treatments (Phillips 1969).

Table 38 EFFECT OF TILLAGE SYSTEM DURING FALLOW FROM WHEAT HARVEST TO SORGHUM PLANTING ON SORGHUM GRAIN YIELDS (from Phillips 1969)

Tillage system [1]	4-year average yield kg/ha
Conventional tillage	2 300 b[2]
Herbicide, no tillage	2 400 b
Herbicide, summer tillage	3 770 a
Herbicide, summer and spring tillage	3 720 a
Herbicide, summer tillage, herbicide at planting	3 800 a
Summer tillage, herbicide, spring tillage	3 370 [3]
Herbicide, summer and spring tillage, herbicide at planting	3 550 [3]

1 Tillage with large V-shaped blade which undercut the surface. Herbicide was atrazine, total amount applied was 3.4 kg/ha.
2 Averages followed by the same letter are not significantly different.
3 3-year averages (not included in statistical analysis).

In Nebraska, tillage-herbicide combinations increased soil water storage during fallow and sorghum yields, but did not significantly affect wheat yields in a wheat-fallow-sorghum (3-year) rotation (Table 39). Soil water storage and wheat yields were increased by tillage-herbicide combination and herbicide only (no-tillage) treatments as compared to a plough treatment in a wheat-fallow (2-year) cropping system (Tables 40 and 41). The yield increases were attributed to the increases in water storage during fallow in both .rotations (Smika and Wicks 1968; Wicks and Smika 1973).

Table 39 EFFECT OF TILLAGE AND HERBICIDE TREATMENTS ON SOIL WATER CONTENTS AT THE END OF THE FALLOW PERIOD [1] AND ON WHEAT AND SORGHUM YIELDS IN A 3-YEAR WHEAT-FALLOW-SORGHUM ROTATION (from Smika and Wicks 1968)

Treatment from wheat harvest to sorghum planting		Treatment from sorghum harvest to wheat planting	Soil water gain [2]	Grain yields	
Fall	Spring			Wheat	Sorghum
			cm	kg/ha	kg/ha
Subtillage	Disk	Subtillage (5)[3]	18.6 b[4]	3 490 a	4 080 b
Subtillage	Atrazine	Subtillage (4)	21.3 ab	3 760 a	4 200 b
Atrazine	Atrazine	Subtillage (4)	21.1 ab	3 630 a	4 580 ab
Atrazine	Atrazine	Contact herbicide (4-6)	22.3 a	3 490 a	4 890 a
Subtillage	Atrazine	Contact herbicide (4-6)	21.6 ab	3 630 a	5 020 a

1 Fallow duration of about 11 months.
2 Determined to a 3 m depth.
3 Values in parentheses denote numbers of operations.
4 Average values in a column followed by the same letter or letters are not significantly different.

Table 40 EFFECT OF TILLAGE AND HERBICIDE TREATMENTS ON SOIL WATER CONTENTS AT THE END OF THE FALLOW PERIOD [1] AND ON WHEAT YIELDS IN A 2-YEAR WHEAT-FALLOW ROTATION (from Smika and Wicks 1968)

Operations during fallow		Soil water gain [2]	Grain yield
Initial operation following wheat harvest	Subsequent operations	cm	kg/ha
Plough	Subtillage (5) [3]	18.6 c[4]	3 090 b
Subtillage	Subtillage (5)	23.8 b	3 360 ab
Atrazine followed by subtillage	Subtillage (5)	27.2 b	3 29O ab
Atrazine	Subtillage (4)	27.5 b	3 360 ab
Atrazine	Contact herbicides (4-6)	32.5 a	3 560 a

1 Fallow duration of about 14 months.
2 Determined to a 3 m depth.
3 Values in parentheses denote number of operations.
4 Average values in a column followed by the same letter or letters are not significantly different.

Table 41 EFFECT OF TILLAGE AND HERBICIDE TREATMENTS ON OPERATIONS TO CONTROL WEEDS, SURFACE RESIDUES, SOIL WATER STORAGE DURING FALLOW [1], AND WHEAT YIELDS IN A 2-YFEAR WHEAT-FALLOW ROTATION (from Wicks and Smika 1973)

Treatment	Operations during fallow: Tillage[2] No.	Herbicide appli-cation No.	Residues main-tained[3] %	Soil water gain [4] cm	Grain yield kg /ha
Plough	8.5	0.0	0	14.6	2 690
Stubble mulch	8.7	0.0	21	20.3	2 880
Atrazine + stubble mulch	7.6	1.4	21	21.5	2 910
Atrazine + contact herbi-cide + stubble mulch	5.1	2.8	25	23.7	3 040
Atrazine + contact herbicide	0.0	6.0	46	27.4	3 170

1 Fallow duration of about 14 months.
2 The plough treatment included one mouldboard ploughing in the spring. Other tillage was with sweep implement.
3 Average amount of residues at start of fallow was 6 600 kg/ha.
4 Determined to a 3 m depth.

Table 42 EFFECT OF TILLAGE SEQUENCES DURING FALLOW ON RESIDUE CONSERVATION, SOIL CLODDINESS, POTENTIAL SOIL LOSS BY WIND, WATER USE BY WEEDS, AND WHEAT YIELD IN KANSAS (USA) (from Woodruff 1972)

Tillage sequence	Surface residues[1] kg /ha	Clods > 0.84 mm in diameter %	Potential soil loss[2] tons/ha	Water loss during fallow[3] cm	Grain yield kg /ha
Sweep; skip[4]; skip; rotary mower plus tandem disk	1 300	58	4.5	12.4	240
One-way disk; skip; skip; rotary mower plus tandem disk	1 200	54	9.0	12.2	260
Sweep; chemical fallow[5]	2 500	65	0.04	7.1	440
One-way disk, one-way disk; skip; rodweeder with chisels	900	50	29.1	5.3	1 400
Sweep; sweep; plain rodweeder; plain rodweeder	1 000	51	16.8	3.0	1 700
One-way disk; sweep; plain rodweeder; plain rodweeder	600	58	28.0	2.5	2 000

1 Amount remaining on surface at the end of fallow.
Computed with wind erosion equation (Woodruff and Siddoway 1965) using indicated cloddiness and residue amounts with a C′ (climatic factor) of 100, K′ (surface roughness) of 1.0; and L′ (field length) of 805 m (2 640 ft).
3 Water loss due to weed growth.
Operations normally performed were skipped.
5 2,4-D herbicide applied at 0.56 kg/ha.

In Kansas, satisfactory control of wind erosion was achieved when more than 1000 kg/ha of residue were maintained on the soil surface (Table 42). However, weed control was poor with the reduced tillage treatments, which resulted in major loss of water due to use by weeds and drastic reductions in wheat yields. The results emphasize the importance of effective weed control if reduced tillage is to be used for erosion control and at the same time produce a favourable crop (Woodruff 1972).

Many fields in eastern Canada are too irregular for contouring and constructing terraces is costly; therefore, vegetation cover and crop residues on the soil surface represent the most effective erosion control measures in that region (Ketcheson 1977). Crop residues maintained on the surface greatly reduced runoff and soil losses when the land was not ploughed. With autumn ploughing, residue removal did not affect runoff, but greatly increased soil losses (Table 43). Elimination of ploughing (no-tillage), however, resulted in lower yields in Canada, with lower temperatures and poorer tilth believed responsible for the yield decline. Maize grain yields on a silty clay loam soil at Guelph, Ontario (Canada), for 1971 to 1975 were 5 140, 5 770 and 6 840 kg/ha with no-tillage; chisel plough in autumn, disk in spring; and mouldboard plough in autumn, disk in spring treatments, respectively (Ketcheson 1977). Similar results were reported by Baldwin (1979), also at Guelph, who evaluated no, minimum and excessive tillage treatments. For no-tillage, maize was planted between the old rows. Minimum tillage involved ploughing, packing and planting, and excessive tillage involved disking twice, ploughing, disking twice again, and planting. Grain yields were 5 560, 6 420 and 6 460 kg/ha with the no, minimum and excessive tillage treatments, respectively.

Table 43 EFFECTS OF PLOUGHING AND MAIZE STOVER ON RUNOFF AND SOIL LOSS FROM GUELPH LOAM (8 PERCENT SLOPE) AT GUELPH, ONTARIO (CANADA)[1]

Treatment	Mean annual losses: May to October, 9-year period		Mean annual losses: November to April, 6-year period	
	Runoff cm	Soil tons/ha	Runoff cm	Soil tons/ha
Stover left on field				
Not ploughed	l.l	3.1	3.1	0.2
Fall ploughed	2.5	24.6	8.2	8.3
Stover removed				
Not ploughed	3.7	38.1	10.6	7.6
Fall ploughed	2.5	40.3	8.3	21.8

1 From Ketcheson 1977. Reprinted with permission from J. Soil and Water Conservation to use copyrighted material.

Water conservation and control of erosion (mainly by wind) are major goals of minimum or reduced tillage systems in the western part of Canada, and residue maintenance on the soil surface is an effective means of reaching these goals. Wheat is the major crop, and tillage-herbicide systems have been shown to conserve more surface residues than tillage systems without adversely affecting yields (Table 44). Where different tillage systems for wheat were compared in Saskatchewan, grain yields differed only slightly among treatments (Table 45) (Johnson 1977).

Table 44 EFFECT OF TILLAGE, HERBICIDES, AND TILLAGE-HERBICIDE COMBINATIONS ON RESIDUE CONSERVATION AND WHEAT YIELDS IN A WHEAT-FALLOW SYSTEM [1]

Treatment: Fall	Treatment: Summer fallow period	Residue conserved percent of original	Yield kg/ha
Nil	Herbicide	62	1 540
Nil	Herbicide-tillage	38	1 490
Nil	Tillage-herbicide	43	1 480
Nil	Tillage	35	1 500
Herbicide	Tillage	37	1 560
Tillage	Herbicide	24	1 510

1 From Johnson 1977. Reprinted with permission from J. Soil and Water Conservation to use copyrighted material.

Table 45 EFFECT OF VARIOUS RESIDUE MANAGEMENT TREATMENTS ON 15-YEAR AVERAGE WHEAT GRAIN YIELDS AT MELFORT, SASKATCHEWAN (CANADA) [1]

Treatment	Yield kg/ha
Plough in fall	1 810
Heavy duty cultivate in fall	2 030
Disk in fall	1 980
Chop straw in fall	1 960
No fall treatment	2 090
Burn in spring	1 960

1 From Johnson 1977. Reprinted with permission from J. Soil and Water Conservation to use copyrighted material.

Chisci and Zanchi (1980) measured runoff and soil losses on a silty clay soil with 12 percent slope near Pisa, Italy. Treatments compared were conventional tillage* (ploughing), minimum tillage (application of paraquat and disking immediately before planting), and lawn-pasture (permanent grass). Each treatment was evaluated on undrained and tile-drained plots. Runoff was highest from the minimum tillage area (Table 46). However, soil loss was highest from the conventional tillage area. Lowest runoff and soil losses occurred from the lawn-pasture areas. Runoff and soil losses were lower from drained than from undrained areas. Although soil losses were not exceptionally high, minimum tillage does minimize the risk of erosion and, thereby, reduces the risk of land degradation.

Table 46 EFFECT OF TILLAGE SYSTEM, CROP AND SOIL DRAINAGE ON RUNOFF AND SOIL LOSSES NEAR PISA, ITALY (from Chisci and Zanchi 1980)

Tillage system and crop	Undrained		Drained	
	Runoff %	Soil loss tons/ha	Runoff %	Soil loss tons/ha
Conventional tillage - wheat	3.6	4.0	2.5	3.7
Minimum tillage - wheat	5.8	1.6	3.8	1.5
Lawn-pasture - forage	3.0	0.18	2.2	0.15

Soil pulverization and high bulk density were factors that contributed to high amounts of runoff and soil losses (Table 47) with a severe-tillage treatment on a sandy clay soil with 3.5 percent slope in Ghana (Baffoe-Bonnie and Quansah 1975). The severe-tillage treatment involved double ploughing, several harrowings to break clods, and several spike-tooth harrowings to provide a very smooth seedbed for seeding. Medium (conventional) tillage consisted of ploughing, harrowing and planting, while light tillage consisted of ploughing and planting. Hand tillage was cultivation with a hoe and cutlass. Although hand and severe tillage resulted in similar bulk densities, runoff and soil loss with severe tillage were significantly higher because of the soil pulverization and smoothing entailed by this method. Lowest density, runoff and soil loss occurred with the light-tillage treatment.

Table 47 EFFECT OF TILLAGE SYSTEM ON SOIL DENSITY, RUNOFF AND SOIL LOSSES FROM A SANDY CLAY SOIL (3.5 PERCENT SLOPE) IN GHANA (from Baffoe-Bonnie and Quansah 1975)

Tillage treatment	Dry soil bulk density [1] 0-7.5 cm depth	7.5-15.0 cm depth	Runoff[2]	Soil loss
	g/cm³		cm	tons/ha
Severe	1.53	1.56	3.12	4.01
Medium	1.36	1.46	0.81	0.91
Light	1.29	1.35	0.33	0.19
Hand	1.52	1.50	1.22	1.40
LSD (0.05)	0.05	0.11	0.38	0.56

1 Values determined after imposing treatments.
2 Total rainfall was 45.2 cm.

Maize yields were not significantly affected in a study in Chile, which included conventional, minimum and no-tillage treatments (Table 48). However, yields tended to be highest with minimum tillage (Treatment B) and lowest with no-tillage (Treatment E). Net returns were highest with minimum tillage (Treatment B) (Luchsinger et al. 1979).

Table 48 EFFECT OF TILLAGE SYSTEMS ON GRAIN YIELDS, COST OF PRODUCTION AND NET PROFITS FROM MAIZE IN CHILE (from Luchsinger et al. 1979)

Treatments [1]	Grain yield kg/ha	Production cost $/ha (US)[2]	Net profit $/ha (US)[2]
A. Plough, harrow; harrow; plant, roll	11 110	58.19	1 705.62
B. Plough; in tandem: harrow, plant, roll	11 230	22.03	1 761.14
C. Plough; in tandem: harrow, plant	10 580	21.80	1 658.04
D. In tandem: harrow, plant	10 810	10.10	1 696.25
E. Plant	9 420	13.20	1 482.20

1 Treatment A is conventional tillage; B, C and D are minimum tillage; and E is no-tillage (with atrazine for weed control).

2 Based on a grain price of $270 per 100 kg (in Chile) and an exchange rate of $17.01 (Chile) per $1 (US), 15 December 1976.

Data presented in Tables 4, 10, 19, 28 and 31 to 48 illustrate that minimum or reduced tillage systems which maintain crop residues on the soil surface for a longer time or throughout the crop production cycle reduce runoff and soil losses, increase water storage in soil during fallow periods, and usually result in crop yields equal to or higher than those obtained with conventional or clean tillage systems. Similar results were obtained with no-tillage, except that yields were lower more frequently with no-tillage than with minimum or reduced tillage when compared with conventional tillage. The no-tillage results are discussed in more detail in the immediately following section.

Improved soil and water conservation is a definite advantage of minimum or reduced tillage systems over conventional or clean tillage systems. Through effective water and especially soil conservation, productivity of land can be maintained for sustained crop production.

Yield decreases with minimum or reduced tillage, although infrequent, occurred at some locations and were usually associated with a particular problem at a given location. Some problems encountered included lower soil temperatures in spring under residues in northern locations in the USA and Canada, greater weed, insect and disease problems, poor seed placement in high-residue situations, and lower nutrient availability. Undoubtedly, dense soil layers could also result in lower yields with minimum or reduced tillage if the soil was not adequately loosened by tillage.

Besides conserving soil and water more effectively and usually maintaining or increasing crop yields as compared with conventional tillage, crop production with minimum or reduced tillage involved fewer cultural operations or less intensive soil manipulation. These factors reduce the amount of labour, tractor and equipment time, and fuel energy required for crop production and, therefore, result in more economical crop production. An improved standard of living and implementation of additional practices for further conservation of soil and water resources are potential benefits from more economical crop production through use of minimum or reduced tillage systems. These systems are included in the economic evaluation of tillage methods in a later section.

A further advantage of minimum or reduced tillage systems as compared with clean tillage is the maintenance of soil organic matter contents at higher levels because of slower decomposition and lower losses in runoff and from soil eroded by wind and water. Whereas minimum or reduced tillage systems maintain crop residues on the soil surface and, therefore, result in slow decomposition of residues, ploughing promotes good soil aeration, rapid decomposition and loss of native organic carbon, and rapid decomposition of residues that are ploughed under (Schnitzer and Khan 1978). Organic matter decreases are especially rapid when tillage thoroughly mixes organic residues with soil.

Nutrients liberated by residue decomposition may be used by subsequent crops, but some are lost by leaching, volatilization and erosion, thus resulting in greater losses than those occurring with conservation tillage systems (Frere 1976; Lal 1975). Examples of nutrient losses in runoff water and in soil eroded from bare slopes are given in Tables 49 and 50, respectively. Nutrient loss in runoff was negligible as compared to organic matter and nutrient loss in eroded soil. For the tropical soil, nutrient losses due to leaching were greater than from runoff. However, any loss of soil and nutrients can result in yield decreases (Lal 1975) and should be avoided to maintain soil productivity. Nutrient losses are especially deleterious in developing countries where little or no fertilizers are applied.

Table 49 NUTRIENT LOSSES IN RUNOFFF WATER
(from Lal 1975)

Slope	Nutrient (kg/ha per year)				
%	N	P	K	Ca	Mg
1	3.9	0.45	4.7	11.2	24.5
5	5.5	0.54	6.2	17.0	2.5
10	5.7	0.77	5.6	14.9	3.1
15	4.5	0.72	4.1	12.5	3.0

Table 50 NUTRIENT LOSSES IN ERODED SOIL
(from Lal 1975)

Slope %	Total organic carbon	Total N	Available P
		kg/ha per year	
1	50	6	0.2
5	870	100	1.8
10	1 850	190	2.2
15	3 070	230	8.1

Some disadvantages of minimum or reduced tillage systems have been previously mentioned, namely, lower soil temperatures, pest problems, poor seed placement, and lower nutrient availability. The lower temperature problem is encountered mainly in cool regions and is of major significance only where the growing season for a crop is relatively short. This problem can be overcome through managing the surface residues or by manipulating the soil. More favourable soil temperatures for seed germination and plant growth can be achieved by removing residues from over the planted row (Van Doren and Allmaras 1978) or by ridging the soil before placing (or growing) residues on the surface (Radke 1982).

Potential pest problems include weeds, insects, plant diseases, rodents and birds. However, except for weeds and possibly rodents, the problems are usually no greater with minimum or reduced tillage than with clean tillage. The disadvantages of minimum or reduced tillage systems are in essence the advantages of clean tillage systems, which were discussed in Section 3.2.4.ii.d.

The minimum or reduced tillage systems as well as other conservation tillage systems involve the maintenance and management of crop residues on the soil surface for controlling runoff and soil erosion, both by wind and water. Therefore, where low amounts of residue are produced or where residues are removed for other purposes or destroyed by insects, minimum or reduced tillage may be no more effective than clean tillage for controlling runoff and erosion. This is illustrated in Table 41 for the stover-removed treatment. Runoff was somewhat higher with the not-ploughed treatment in both periods. Although soil losses were higher with the autumn ploughed treatment in both periods, the difference was relatively small in the May to October period.

c. No-tillage

No-tillage for this report is synonymous with no-till, zero-tillage, slot planting, ecofallow, sod planting, chemical fallow, and direct drilling, which frequently appear in the literature and are satisfactorily covered by the definition given by the SCSA (1982). According to this definition, no-tillage is a method of planting crops that involves no seedbed preparation other than opening the soil for the purpose of placing seed at the desired depth (Fig. 86). This involves opening a small slit or punching a hole in the soil to place the seed. Usually the crops are not cultivated and chemicals are normally used to control weeds. For practical purposes to facilitate crop planting, up to 25 percent of the surface area can be disturbed or tilled in a no-tillage system (Lessiter 1982a). One shallow disking (no deeper than 7.5 cm) is sometimes necessary to establish a cover crop or to cut crop residues in no-tillage systems (Lessiter 1982b).

Fig. 86 Maize establishment by no-tillage method in wheat stubble (photo provided by A.F. Wiese, Texas Agric. Exp. Stn.)

Probably the first experiment involving no-tillage was reported by Garber in 1927 (cited by Baeumer and Bakermans 1973i. In that experiment, Garber successfully overseeded a legume into an unproductive grass sod without tilling the soil. The grass was closely grazed or burned and heavy seeding rates were used to reduce competition between the unwanted grass and surface-sown forage species. Trampling by grazing animals assisted in bringing seeds in close contact with soil. This experiment illustrated the essential features of a successful no-tillage system, which are to grow a crop with a minimum amount of soil disturbance and to control unwanted vegetation by other than mechanical methods. Such a system became feasible in the 1950s when chemicals were introduced which destroyed existing vegetation and had a relatively short or no residual effect on the crop to be established (Baeumer and Bakermans 1973).

No-tillage was initially used for pasture renovation. By the 1940s, reports indicated its use to control weeds in citrus orchards in California (Johnston and Sullivan 1949; Lonbard 1944). In the 1950s, no-tillage research with field crops was initiated at several locations in the USA (Baker et al. 1956; Barnes and Bohmont 1958; Barnes et al. 1955; Phillips 1954; Wiese and Army 1958, 1960; Wiese et al. 1960). Research with no-tillage was greatly expanded after the system became widely publicized in the late sixties and early seventies. Since then, many aspects of no-tillage have been investigated for numerous crops at research locations throughout the world and suitable systems have been developed for many crops. Areas devoted to no-tillage crop production on a worldwide basis are not known, but the system is used on about 3.0 million hectares in the USA (Lessiter 1982a).

A vast amount of information has been published in recent years concerning no-tillage systems. A detailed analysis and discussion of all information is beyond the scope of this report. However, the literature will be relied on heavily to document the advantages and disadvantages ascribed to the no-tillage system of crop production.

Advantages ascribed to no-tillage systems as compared with clean and even with other conservation tillage systems include improved control of wind and water erosion, increased use of land, improved water conservation, equal or higher crop yields, reduced energy requirements, reduced labour requirements, reduced equipment inventories, reduced wear and tear on tractors and equipment, and greater net returns.

The value of surface residues to control soil erosion by wind and water has been emphasized in earlier sections of this report, and the approximate amounts of different types of residue needed to keep soil losses at tolerable levels (11.2 tons/ha) on various types of soil are given in Table 25. However, even a loss of 11.2 tons/ha is land degrading under some conditions, such as on shallow or sloping soils, and should be avoided if possible. The no-tillage system has been shown to reduce soil losses as compared with clean tillage and, in many cases, even as compared with other conservation tillage systems (Tables 4, 8, 10, 11, 12, 31, 32, 43 and 46). This tremendous value of no-tillage for reducing soil losses, provided adequate residues are maintained on the soil surface, has been widely recognized and the system recommended and promoted for use where the potential for soil erosion exists.

The tables mentioned in the foregoing paragraph pertained to the effects of no tillage on water erosion. No-tillage, however, is also highly effective for controlling wind erosion and some examples of the effects are included in Tables 51, 52 and 53.

The results shown in Table 51 illustrate the value of increasing amounts of surface residue for decreasing wind erosion. No-tillage and reduced tillage consistently reduced soil losses on the sandy-textured soils. However, the large amounts of surface residues could reduce soil temperatures and possibly reduce crop yields on the poorly drained, dark, sandy loam soils (Woodruff 1972).

Tests with a portable wind tunnel in Ohio and Wisconsin on loamy fine sands and loamy sands, respectively, showed major advantages of the no and reduced tillage methods to control wind erosion (Tables 52 and 53). Again, surface residues were primarily responsible for the reduced soil losses, but slightly wetter soil surfaces, more nonerodible clods, and greater soil roughness in the reduced tillage areas contributed to the reduced soil losses (Woodruff 1972).

Table 51 EFFECT OF TILLAGE SYSTEM ON SOIL EROSION BY WIND WITH MAIZE STALKS ON LAND IN NORTHWESTERN OHION (USA) (from Woodruff 1972)

Tillage system	Surface residues tons/ha	Soil loss
Experiment I [1]		
Fall (autumn) plough	0.28	26.1
Spring plough	0.12	8.5
No-tillage	5.60	1.2
Experiment II [2]		
Plough, normal residue	0.14	3.5
Disk, normal residue	0.54	5.1
Disk, double residue	1.76	0.8
No-tillage, no residue	0	3.0
No-tillage, normal residue	1.82	0.6
No-tillage, double residue	2.85	0.5

1 Comparison of autumn and spring ploughing and no-tillage.
2 Comparison of ploughing with normal residues and disk and no-tillage with no, normal or double residues.

Table 52 EFFECT OF LAND PREPARATION ON SOIL EROSION BY WIND ON NEWLY PLANTED MAIZE FIELDS IN NORTHWESTERN OHIO (USA), MAY 1967 (from Woodruff 1972)

Land preparation	Soil type	Soil loss tons/ha
Ploughed and planted	Ottokee loamy fine sand	403.0
Power disked and planted	Oakville loamy fine sand	7.6
No-tillage and planted	Spinks loamy fine sand	1.3
Untilled maize-stalk field	Oakville loamy fine sand	0.8

Table 53 EFFECT OF LAND PREPARATION ON SOIL EROSION BY WIND ON NEWLY PREPARED OR PLANTED MAIZE FIELDS IN CENTRAL WISCONSIN (USA), MAY 1969 (from Woodruff 1972)

Land preparation	Soil type	Soil loss tons/ha
Ploughed and planted	Plainfield loamy sand	188.0
Disked and planted	Boone-Hixton loamy sand	62.7
Ploughed and planted - crust broken	Plainfield loamy sand	44.8
No-tillage and planted	Richfield loamy sand	33.6
Untilled maize-stalk field	Plainfield loamy sand	6.7
Disked winter-killed oats	Plainfield loamy sand	1.8
Standing chemically killed rye	Plainfield loamy sand	0.09

The potential for controlling erosion should be an adequate incentive by itself to use the no-tillage system. An added incentive linked to erosion control is the potential for producing crops safely on lands that are unsuitable for crop production by conventional or clean tillage methods. For example, Class II and III land (Table 2) can be cropped as intensively as Class I land because of reduced erosion by water. Therefore, farmers, can extend their crop areas to land which is subject to erosion by clean tillage, but which is adequately protected when the no-tillage system is used (Phillips 1980[?]). Adoption of the no-tillage system has potential for greatly increasing food supplies on a worldwide basis because of the expanded areas that can be safely used for crop production with this system.

The reductions in water erosion with no-tillage systems are related to reduced runoff and to the surface cover provided by residues, which reduces soil detachment and transport due to raindrop impact and flowing water. Consequently, soil losses are usually reduced to a greater extent than runoff by use of no-tillage cropping systems (Tables 8, 12, 31, 32, 43 and 46). The lower reduction in runoff than soil loss is also due to filling of the profile with water, which prevents storage of additional water, and to soil profile characteristics, which reduce the water infiltration rate into soil. Reduction in runoff, however, aids in replenishing the soil water supply or maintaining it at a higher level. Further conservation of water through no-tillage is achieved when surface residues reduce the evaporative losses of soil water.

The water-conserving benefits of no-tillage systems have been widely demonstrated and reported in the literature. Some representative examples of increased water conservation (less runoff and lower evaporation) have been shown in Tables 8, 12, 13, 28, 31, 32, 39, 40, 41 and 43).

Reduced runoff *per se* does not necessarily mean that more water will be stored in the soil for subsequent plant use because a soil is capable of retaining only a given amount of water with the excess either percolating through the soil profile or seeping from the soil at downslope positions. The amount retained depends on such factors as soil texture, porosity, layering, depth and organic matter content. While reduced runoff does not increase water storage to an amount above a soil’s storage capacity, it does increase the potential for more readily refilling the storage reservoir after plants have used some of the water. Therefore, reduced runoff can greatly influence crop yields due to water conserved during the growing season.

Evaporation accounts for the major loss of water from many cultivated soils, especially in arid to semi-arid regions. For example, about 60 percent of the 50 cm or average annual precipitation in the Great Plains (USA) is lost directly from soil by evaporation (Bertrand 1966). Evaporation decreases and transpiration increases as plant canopies develop. Evaporation can also be decreased by maintaining adequate crop residues or mulching materials on the soil surface, as with no-tillage systems.

Soil water evaporation occurs in three stages (Lemon 1956). Water loss is rapid and steady in the first stage, and depends on the net effects of water transmission to the surface and on such environmental conditions as windspeed, temperature, relative humidity and radiant energy. The loss rate decreases rapidly during the second stage as the soil water supply is depleted. During this stage, soil factors control the rate of water movement to the surface and above-ground factors have little influence. Evaporation during the third stage is extremely slow and is controlled by adsorptive forces at the liquid-solid interface.

The greatest potentials for decreasing evaporation of soil water lie within the first two stages (Lemon 1956). Potential methods include (a) decreasing turbulent transfer of water vapour to the atmosphere, (b) decreasing capillary continuity, and (c) decreasing capillary flow and water-holding capacity of surface soil layers.

The effect of a surface mulch to reduce evaporation of soil water has long been recognized (Russel 1939). Since then, many materials have been evaluated as potential mulches for reducing evaporation. The effect of mulches on evaporation, however, is difficult to establish because of interacting influences on water infiltration, distribution, and subsequent evaporation. Higher water contents resulting from surface mulches may be due to lower evaporation, but water infiltration and distribution may also be involved, especially under field conditions where there is little control over soil wetting by precipitation (Unger and Stewart 1983).

Although many mulching materials have been evaluated and found effective for reducing evaporation, most are not practical for widespread application under field conditions. Use of crop residues as mulches, however, is generally practical and effective if adequate amounts of residue are available.

Field studies in Colorado, Montana and Nebraska (USA) showed that the amount of precipitation stored as soil water during fallow from wheat harvest until sorghum planting 10 or 11 months later increased from 16 percent of the total with no residues to 34 percent with 11 tons/ha of wheat straw on the surface (Greb et al. 1967). At Bushland, Texas, storage of precipitation as soil water during the 10 to 11 month fallow ranged from 23 percent with no mulch to 46 percent with 12 tons/ha of mulch (Table 13) (Unger 1978a). Also at Bushland, Unger and Wiese (1979) used no, sweep and disk tillage for residue management and weed control during fallow from harvest of irrigated winter wheat until planting of dryland sorghum for grain about 11 months later. Precipitation storage during fallow, sorghum grain yields and water use efficiency for grain production were highest with no-tillage and lowest with disk tillage (Table 54).

Table 54 EFFECT OF TILLAGE METHOD ON PRECIPITATION STORAGE, SORGHUM YIELD, WATER-USE EFFICIENCY, AND ENERGY USE FOR SORGHUM IN A WHEAT-SORGHUM CROPPING SYSTEM IN TEXAS (USA)

Tillage method	Precipitation storage[2] %	Grain yield kg/ha	Grain yield ET water-use efficiency kg/ha-cm	Energy use litres/ha[3]
No-tillage	35	3 140	89	18
Sweep	23	2 500	77	26
Disk	15	1 930	66	37

1 From Allen et al. 1981; Unger and Wiese 1979. Reprinted with permission from Am. Soc. Agric. Eng. to use copyrighted material.
2 Precipitation was: fallow 34.8 cm; growing season 26.4 cm.

3 Diesel fuel equivalent for tillage and seeding; includes energy to manufacture and apply herbicides.

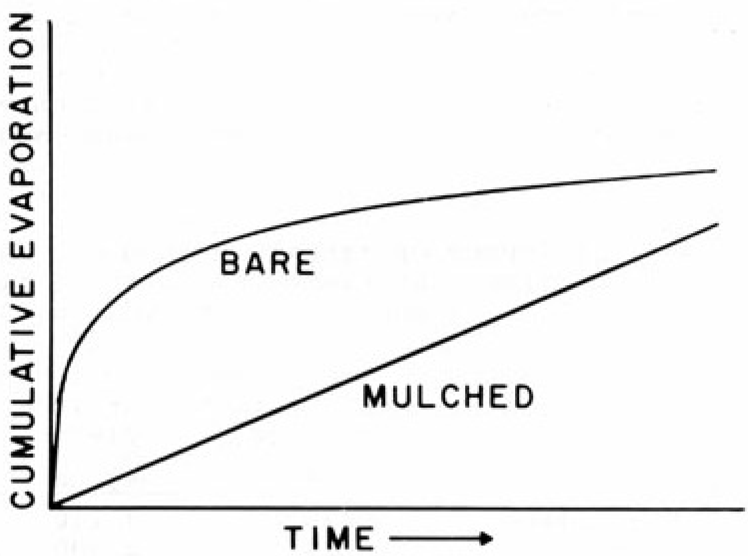
Similar results have been reported from other locations (Tables 39, 40 and 41). Water infiltration and distribution as well as evaporation control were undoubtedly involved in the increased water conservation in these studies which showed that maintaining crop residues on the soil surface as a mulch by use of no-tillage cropping systems can greatly increase the storage of precipitation as soil water.

One property of mulches that affects their effectiveness to decrease evaporation is the thickness of a given amount of mulching material (Bond and Willis 1969; Hanks and Woodruff 1958; Unger and Parker 1976). Evaporation decreases as mulch thickness increases. The density of the material greatly influences the thickness of randomly placed mulches such as crop residues. A low-density material such as wheat straw more effectively decreases evaporation than more dense ones such as sorghum stubble or cotton stalks. About twice as much sorghum stubble and four times as much cotton stalks were needed as compared with wheat straw on a weight basis to achieve similar decreases in evaporation (Unger and Parker 1976).

Mulches of crop residues effectively reduce first stage evaporation (Bond and Willis 1969; Unger 1976; Unger and Parker 1976). However, enough water must be added to penetrate deeply into the soil or large amounts of residue must be present to reduce evaporation on a long-term basis (Bond and Willis 1971; Gardner and Gardner 1969; Unger 1976; Unger and Phillips 1973). Although mulches reduce initial evaporation rates, evaporation at the initial rate is continued for a longer time and cumulative evaporation with mulches eventually becomes similar to that from bare soil (Bond and Willis 1969, 1970, 1971; Unger 1976; Unger and Phillips 1973). Cumulative evaporation from bare and mulched soils is shown schematically in Fig. 87 (Unger and Phillips 1973), which illustrates that a mulched soil would contain more water than a bare soil until the curves meet or cross, provided both soils contained equal amounts of water initially.

Fig. 87

Schematic diagram showing cumulative evaporation from a bare and a mulched soil as influenced by time (from Unger 1973)



The additional water conserved by no-tillage systems, where crop residues are maintained on the soil surface as a mulch, has variable effects on crop growth and yields, depending on the region and, to some extent, on soils within the region. In arid and semi-arid locations, additional water can improve crop growth and yields; in subhumid and humid locations, it is usually less beneficial, but may have a major impact on yields when crops experience short-term droughts. It adversely affects crops on poorly drained soils in any region, but this problem is most severe in wetter regions. Additional water may also affect crop production adversely in cool locations because of slower warming of wet soils.

Crops usually experience water stress at some time during the growing season in semi-arid locations, such as the Great Plains and Pacific Northwest regions in the USA, where growing season precipitation is limited and erratic and much of the crops’ water supply is derived from water stored in soil at planting time. The amount stored has a major impact on crop yields. For example, grain yields of spring wheat increase about 65 kg/ha for each additional centimetre of water stored in the soil profile at planting time. The increase is about 72 kg/ha for winter wheat (Johnson 1964). Yields of sorghum for grain increase about 170 kg/ha for each additional centimetre of soil water at planting (Jones and Hauser 1975).

Soils are not usually filled to capacity with water at planting time in the Great Plains and Pacific Northwest (USA) where clean and minimum or reduced tillage systems are used. Limited soil water contents at crop planting also constrict crop yields under dryland conditions in semi-arid regions throughout the world. Consequently, means to increase soil water contents at crop planting have long been sought. Use of the stubble mulch tillage system, which maintained some crop residues on the surface as a mulch, resulted in greater water conservation and crop yields than clean tillage, but practical methods for maintaining most crop residues as surface mulches, effectively controlling weeds without tillage, and planting crops in residues were not available until the development and introduction of no-tillage systems.

Using no-tillage systems has increased soil water storage during non-cropped periods and subsequent crop yields. Some examples have been given in Tables 13, 28, 39, 40 and 41. Other examples of soil water contents and crop yields being equal or better with no-tillage than with clean or stubble mulch tillage were reported by Aase and Siddoway (1980), French and Riveland (1980), Hamblin and Tennant (1979), Rai and Yadav (1979), Shieferstein (1980), and others. Common characteristics of all these studies were good to excellent control of weeds and volunteer crop plants, and maintenance of crop residues on the soil surface. Soil water storage and crop yields were lower with no-tillage than with other tillage methods when weed control was poor or crop residues were removed from the no-tillage areas (Hadas et al. 1980; Hakimi and Kachru 1976; Mahto and Sinha 1980; ODA 1982; Shaalan et al. 1977; Woodruff 1972; see Table 42). These results emphasize the tremendous importance of effective weed control to conserve water and obtain good crop yields with no-tillage in semi-arid regions. Even widely-spaced weeds can seriously hinder water conservation because the roots of some weeds extend up to 4 m radially from the plant base (Davis et al. 1965, 1967). Examples of rooting patterns, soil water extraction and top growth of some weeds and sorghum were given by Davis et al. (1965) (see Table 55).

In contrast to semi-arid regions, soil water contents and precipitation are usually adequate for favourable crop yields in subhumid to humid regions. However, droughts of relatively few days duration can greatly reduce crop yields on soils that have little water storage capacity or in which the rooting depth is restricted. Water storage capacity may be limited by soil texture and depth while plant rooting may be restricted by compacted layers, such as plough pans, fragipans, clay pans, or other naturally dense layers, or by soil horizons that are chemically unfavourable to root growth

Table 55 ROOTINIG PATTERNS, SOIL WATER EXTRSACTION AND TOP GROWTH FOR SOME WEEDS AND SORGHUM
(from Davis et al. 1965)

Plant	Root depth	Ront spread[1]	Root profile area [2]	Water extracted above rainfall	Top growth
	m	m	m^2	kg/plant	g/plant
Kochia [4]	1.2	1.8	1.9	7.3	72
Pursh lovegrass	1.2	1.8	1.9	7.8	36
Buffalobur	1.2	1.8	2.2	12.3	113
Crabgrass	1.2	3.0	2.2	13.7	68
Puncturevine	1.2	3.0	2.6	17.1	177
Russian thistle	1.5	1.8	2.8	14.6	181
Palmer amaranth	1.8	3.0	3.3	9.6	109
Sorghum	1.2	3.0	3.3	18.3	181
Cocklebur	1.2	4.3	4.1	30.9	136

1 Maximum width of root water extraction profile.
2 Cross sectional area of root water extraction profile.
3 Based on a plant spacing of 15 cm in the planted row.
4 See Appendix 6 for scientific names.

(high salt content, low pH, high exchangeable aluminium content, etc.). At other times, precipitation may not be adequate to supply the plants' needs.

Where water storage or root growth limiting conditions prevail, the soil water reservoir must be replenished often to avoid plant water stress. Reduced runoff with no-tillage more readily refills the soil water storage reservoir while reduced evaporation results in more of the water being available for plant use. These conditions increased soil water contents and crop yields with no-tillage in years when rainfall was limited (Adams et al. 1970; Beale and Langdale 1964; Carreker et al. 1972; Kamara 1980; Khan and Chatterjee 1982; Lal 1975; Sanchez 1977; Unger and Phillips 1973; Viator and Marshall 1981). No-tillage usually resulted in yields equal to or higher than those with other tillage methods when precipitation was adequate and other conditions were favourable (Tables 33, 37, 44 and 47; Hundal and De Datta 1982; Lal 1975). However, as in semi-arid regions, effective weed control and maintenance of surface residues were essential to conserve water and obtain favourable crop yields with no-tillage. With poor weed control or limited residues, water storage and yields were usually lower with no-tillage than with other tillage methods (De Datta et al. 1979; Dunham 1981 [?]; Kang et al. 1980; Luchsinger et al. 1979; Stoinev and Onchev 1980). Other factors contributing to poor yields with no-tillage where water was adequate were surface compaction (Dunham 1981 [?]), N stress (Kang et al. 1980), poor soil tilth (Ketcheson 1977), and poor plant establishment (Unger 1977).

Excessive soil water contents due to no-tillage have resulted in lower crop yields on some medium to heavy-textured soils (Tables 33, 34 and 36), with poor aeration (Baeumer and Bakermans 1973) and slow soil warming (Triplett and Van Doren 1977) being possible reasons for poor plant performance under these conditions. Because of these problems, no-tillage is usually not recommended for poorly-drained soils (Triplett and Van Doren 1977).

A cooler soil under no-tillage with a mulch could be a problem in cool climates where there may be delays of several clays before temperatures favourable for germination and seedling establishment are reached (Unger and Stewart 1976). In Iowa (USA), a mulch of chopped maize stalks applied at rates from 0 to 9 tons/ha lowered soil temperatures at a 10 cm depth by an average of 0.4oC per ton of mulch in May and June, which caused delays in maize planting (Burrows and Larson 1962). Similar temperature decreases were found at other northern USA Locations (Allmaras et al. 1964; Van Wijk et al. 1959; Willis et al. 1957), which decreased early maize growth. In some places in southern USA, surface mulches had little or no effect on early growth of crops planted in the spring (Adams 1962, 1965, 1967, 1970; Unger 1978b; Van Wijk et al. 1959), even though soil temperatures were lower under mulches than in bare soil. The effect of mulch rate on soil temperature during different seasons of the year at a relatively warm USA location is shown in Fig. 88 (Unger 1978b). The high mulch rates resulted in lower soil temperatures at planting, which slightly retarded germination and seedling emergence of sorghum. However, subsequent growth and yields of sorghum on high-mulch plots exceeded that on bare soil or low-mulch plots because more water had been stored in the high mulch plots (Table 13) (Unger 1978a). Where cool soil temperatures are a problem with no-tillage systems, as in the northern USA, Radke (1982) found that ridging the soil for the previous crop resulted in warmer temperatures in the ridges where the next crop was planted the following spring than where the land was managed in a flat condition.

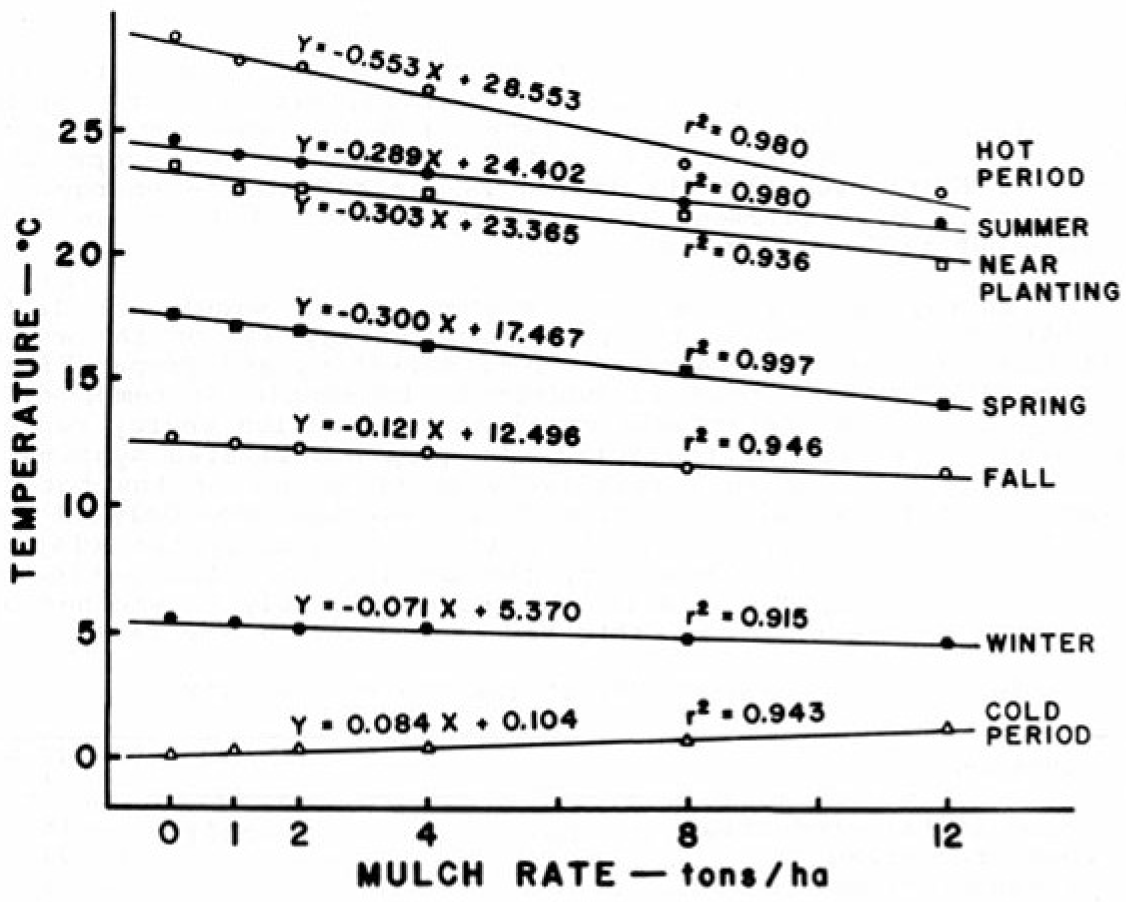


Fig. 88 Relationships between mean soil temperatures and straw mulch rates for different seasons of the year and for a hot, a cold, and a near-sorghum-planting period at Bushland, Texas (USA) (from Unger 1978a)

In hot climates or during hot weather, cooler soil temperatures with no-tillage than with clean tillage aided crop establishment and seedling growth. In Nigeria, the soil temperature at a 5 cm depth 2 weeks after planting sorghum was 4loC with clean tillage. When sorghum was no-tillage planted through 1 to 2 cm of crop residue, the maximum temperature was only 3loC. The lower temperature improved germination and seedling vigour, and increased yields by 50 percent because of lower plant water stress (Rockwood and Lal 1974).

Allen et al. (1975) measured soil temperatures in clean and no-tillage plots planted to sorghum (double-cropped) after wheat harvest in late June or early July in the Texas High Plains (USA) . In 1968, when maximum air temperatures averaged 38oC during the seedling emergence period, soil temperatures were lower in wheat stubble (no-tillage) plots than in tillage plots. The lower temperatures contributed to lower evaporation, which caused the soil to remain moist longer and improved the microclimate for germination, seedling establishment and plant growth. Soil surface temperatures reached 37ºC in clean tillage plots in 1973, but only 32°C in no-tillage plots. The higher temperatures in bare soil contributed to poor sorghum germination, emergence and seedling vigour.

The reduced energy requirement with no-tillage is related to the fewer cultural operations required as compared with other tillage systems. Because of fewer operations, there are associated reductions in labour requirements, equipment inventories, and tractor and equipment wear and tear. The above factors are all related or interact with each other; therefore, they are discussed simultaneously in the following paragraphs.

The amount of energy and labour expended and equipment required to produce a crop varies, among other factors, with the crop produced, soil type and condition, climate, and tillage method used. A detailed discussion of all factors is beyond the scope of this report. Therefore, the discussion is limited to the energy, labour or tractor and equipment requirements with no-tillage as compared with other tillage systems.

Total energy used in the food system varies widely in different countries, depending on the production energy and on the amount of off-farm processing, transportation, marketing and preparation that is involved before food is consumed. In simple systems, off-farm energy use may be relatively small and production energy represents a large proportion of the total. In more complicated systems, food production may require a relatively small amount of the total. For example, agricultural production on the average uses only 18 percent of the total energy expended in the USA food system (Table 56) (Allen et al. 1977). However, the amount used for agricultural production is highly variable and depends largely on whether or not the crops are fertilized, irrigated, and dried on the farm.

Table 56 ENERGY USE IN THE USA FOOD SYSTEM[1]

Function	Energy used
	%
Agricultural production	18
Food processing	33
Transportation	3
Wholesale and retail	16
Household preparation	30

1 From Allen et al. 1977. Reprinted with permission from J. Soil and Water Conservation to use copyrighted material.

Tillage energy represents a relatively small portion of the total amount used for irrigated crop production, ranging from 1.2 percent with no-tillage to 4.8 or 7.6 percent with some more intense tillage systems (Tables 57 and 58) (Allen et al. 1977; Howard 1981). Any saving in fuel for tillage leads to more economical crop production, provided crop yields are not reduced when energy-conserving tillage systems are used. Even greater savings would occur if the amount of energy used for pumping water could be reduced because of more effective conservation and use of irrigation water or precipitation in the crop production system. This was achieved by Musick et al. (1977) when sorghum was planted in disk and no-tillage plots. Because of greater water storage from precipitation with no-tillage before planting, less irrigation water was needed on no-tillage than on disk tillage plots to obtain comparable yields.

Table 57 FUEL ENERGY REQUIRED FOR SURFACE IRRIGATED AND DRYLAND GRAIN SORGHUM TILLAGE SYSTEMS, BUSHLAND, TEXAS[1, 2]

Operation	Irrigated				Dryland	
	Disk-chisel	Disk	Bed Split	Bed Mulch	Wheat-fallow-sorghum	Continuous sorghum
Tillage and planting	68.3	57.1	31.8	23.4	41.2	28.1
Fertilizer[3]	196.4	196.4	196.4	196.4	-	-
Herbicide	10.3	10.3	10.3	10.3	4.7	4.7
Irrigation[4]	600.0	600.0	600.0	600.0	-	-
Harvest	11.2	11.2	11.2	11.2	7.0	6.5
Transportation[5]	7.5	7.5	7.5	7.5	1.9	1.4
Total	893.7	882.5	857.2	848.8	54.8	40.7
Till and plant, % total	7.6	6.5	3.7	2.8	75.2	69.0

1 From Allen *et al.* 1977. Reprinted with permission from J. Soil and Water Conservation to use copyrighted material.

2 Assumed yields of 7 280 kg/ha irrigated sorghum; 1 680 kg/ha (wheat-fallow-sorghum rotation); and 1 230 kg/ha (continuous) dryland sorghum.

3 168 kg/ha N as NH_3 - 1.17 litre diesel fuel/kg N equivalent for NH_3.

4 51 ha-cm (20 acre-inches), 64 metre pump lift, 75 percent pump efficiency, 95 percent gear head efficiency.

5 16 ton load, 16 km to market, 1.7 km/litre.

In contrast to irrigated systems at Bushland, Texas (USA), energy use for tillage in nonirrigated (dryland) systems represents the major share of the total amount required (Table 57). The percent for tillage was high because no energy was required for irrigation or for fertilizers. Dryland crops at the Texas location have not responded to fertilizers. At locations where crops require fertilizers, the share of the total for tillage would consequently decrease.

Table 58 FUEL ENERGY REQUIRED TO PRODUCE IRRIGATED MAIZE WITH CONVENTIONAL AND NO-TILLAGE IN NEBRASKA (USA)

Operation	Diesel fuel equivalent Conventional tillage	No-tillagge
	litres/ha	
Tillage and planting	38.4	9.4
Fertilizers (commercial)	282.5	282.5
Herbicide and insecticide	10.3	13.1
Irrigation	289.0	289.0
Harvest	10.3	l0.3
Drying	128.1	128.1
Transportation	28.1	28.1
Total	786.7	760.5
Tillage and planting, % of total	4.8	1.2

1 From Howard 1981. Reprinted with permission from Am. Soc. Agric. Eng. to use copyrighted material.

Table 59 DIESEL FUEL REQUIREMENTS FOR SELECTED FIELD OPERATIONS[1]

Operations	Soil draught requirements[2] Low	Moderate	High
		litres/ha	
Shredding cornstalks	7.02	7.02	7,02
Subsoil chiselling 35.6 cm (14 in)	12.16	19.64	27.59
Mouldboard ploughing 20.3 cm. (8 in)	10.76	17.30	24.32
Chiselling 20.3 cm (8 in)	7.02	11.69	16.37
Offset disking	5.61	8.89	12.63
Field cultivation, ploughed ground	5.14	5.61	6.08
Tandem disking, ploughed ground	4.68	5.14	5.61
Tandem disking, 2nd trip	4.21	4.68	5.14
Tandem disking, cornstalks	3.74	4.21	4.68
Forming ridges, fall (autumn)	3.74	4.21	4.68
Harrowing, spring tooth	3.27	3.74	4.21
Harrowing, spike tooth	3.27	3.27	3.27
NH application, no-till ground	6.08	9.82	13.56
NH3 application, ploughed ground	5.61	6.55	7.48
Field cultivating + planter	8.89	9.82	10.76
Strip rotary till + planter	7.95	8.89	9.82
Planting, wheel-track	5.61	6.08	6.55
Planting, conventional	3.74	4.68	5.61
Planting, till	3.74	4.68	5.61
Planting, no-till	3.74	4.68	5.61
Cultivating, disk hiller	3.27	3.74	4.21
Cultivating, sweeps	2.81	3.27	3.74
Cultivating, rolling tines	2.81	3.27	3.74
Rotary hoeing	2.34	2.34	2.34
Spraying fertilizer	1.87	1.87	1.87
Spraying pesticides	1.40	1.40	1.40

1 From Griffith and Parsons 1981. Reprinted with permission from Am. Soc. Agric. Eng. to use copyrighted material.

2 Fuel requirements given are averages of tests conducted over a wide range of soils. The actual fuel requirements for a particular field operation in a particular soil type may vary as much as 25 percent or more from the values given. Soil types associated with the draught ratings include: Low - sands and sandy loams; Moderate = loams and silt loams; High = clay loams and clays.

The diesel fuel equivalents in Tables 57 and 58 represent values for various segments of the total crop production system. Values for selected field operations on soils of differing draught requirements are given in Table 59 (Griffith and Parsons 1981). Large amounts are indicated for the major tillage operations, namely, ploughing, chiselling, disking, NH application with no-tillage, and field cultivating plus planting[3], with relatively large increases for these operations as compared to others with increases in draught requirement. Data in Table 59 can be used to estimate the fuel requirement for various tillage systems, provided the operations required are known. However, actual fuel requirements for tillaqe on a particular soil may vary 25 percent or more from the given values (footnote, Table 59).

Values different from those in Table 59 were reported for other locations. An example for nine tillage systems in Michigan (USA) is given in Table 60, which indicates the diesel fuel requirement for various operations and totals for the systems as well as total number of operations required. The reduced tillage systems and especially the no-tillage system greatly reduced the fuel requirement as compared with conventional tillage (Robertson and Mokma 1978).

Table 60 ESTIMATED DIESEL FUEL REQUIREMENTS FOR PLANTING MAIZE IN NINE TILLAGE SYSTEMS (from Robertson and Mokma 1978)

	Tillage system								
	1	2	3	4	5	6	7	8	9
Tillage operation	Conventional tillage		Reduced tillage	Plough and plant	Plough plant	Chisel plough	Tandem disk	Rotary plough	No-tillage
	litres/ha								
Mouldboard plough	17.0	-	-	17.0	-	-	-	-	-
Plough with trailing tool	-	-	19.6	-	-	-	-	-	-
Chisel plough	-	10.5	-	-	-	-	-	-	-
Chisel plough	-	10.5	-	-	-	10.5	-	-	-
Disk harrow	5.9	5.9	-	-	-	-	7.2	-	-
Disk harrow	4.6	4.6	-	-	-	-	4.6	-	-
Drag harrow	3.9	3.9	-	-	-	3.9	3.9	-	-
Drag harrow	2.6	2.6	-	-	-	-	-	-	-
Spray[1]	a	1.0	a	a	a	a	a	a	1.0
Rotary plough	-	-	-	-	-	-	-	19.6	-
Plant[2]	5.9	5.9	5.9	5.9	-	5.9	5.9	5.9	5.9
Plough-plant[3]	-	-	-	-	18.7	-	-	-	-
Total	39.9	44.9	25.5	22.9	18.7	20.3	21.6	25.5	6.9
No. of operations	6	8	2	2	1	3	4	2	2

[1] a = bandspray with planter.

[2] 76 cm rows.

[3] 107 cm rows.

Table 61 DIESEL FUEL AND LABOUR REQUIREMENTS FOR VARIOUS TILLAGE SYSTEMS[1]

Operation	Tillage systems					
	Mouldboard plough	Chisel lough	Disk	Rotary till	Till Plant	No Tillage
	- Fuel requirement, litres/ha					
Chop stalks	-	-	-	-	5.14	-
Mouldboard plough	21.04	-	-	-	-	-
Chisel plough	-	9.82	-	-	-	-
Fertilize, knife	5.61	5.61	5.61	5.61	5.61	5.61
Disk	6.92	6.92	6.92	6.92	-	-
Disk	6.92	6.92	6.92	-	-	-
Plant	4.86	4.86	4.86	13.28	6.36	5.61
Cultivate	4.02	4.02	4.02	4.02	4.02	-
Spray (2)	-	-	-	-	-	4.30
Total	49.37	38.15	28.33	29.83	21.13	15.52
	—Labour requirement, hours/ha -					
Chop stalks	-	-	-	-	0.42	-
Mouldboard plough	0.94	-	-	-	-	-
Chisel plough	-	0.52	-	-	-	-
Fertilize, knife	0.32	0.32	0.32	0.32	0.32	0.32
Disk	0.40	0.40	0.40	0.40	-	-
Disk	0.40	0.40	0.40	-	-	-
Plant	0.52	0.52	0.52	0.99	0.62	0.62
Cultivate	0.44	0.44	0.44	0.44	0.44	-
Spray (2)	-	-	-	-	-	0.54
Total	3.02	2.60	2.08	2.15	1.80	1.48

1 From Dickey and Rider 1981. Reprinted with permission from Am. Soc. Agric. Eng. to use copyrighted material.

Table 62 ENERGY REQUIRED T0 PRODUCE MAIZE UNDER CONVENTIONAL (CLEAN), CHISEL AND NO-TILLAGE SYSTEMS (from Griffith and Parsons 1980)

Input item[1]	Tillage system			
	Clean	Chisel	No-tillage	No-tillage (2)
	diesel fuel equivalent, litres/ha			
On-farm fuel	46.8	36.9	16.8	13.6
Machinery	24.0	23.2	9.8	9.4
Herbicides	16.4	18.8	26.9	26.9
Nitrogen[3]	248.3	248.3	248.3	385.6
Total	335.5	327.2	301.8	435.5
Savings vs. clean	-	+ 8.3	+ 33.7	- 100.0

1 Only those energy-consuming items likely to be altered by tillage system are listed.
2 For manufacture and maintenance.
3 168 kg/ha N as anhydrous ammonia for all systems, except that 200 kg/ha N surface applied as 28% liquid for no-tillage (2) system.

An example for six tillage systems in Nebraska (USA) is given in Table 61. For these systems, corresponding labour requirements are included in the table. The fuel requirement for the no-tillage systems was less than one-third the requirement for the mouldboard plough system. The labour requirement was only about half the requirement for mouldboard ploughing (Dickey and Rider 1981).

The reduction in fuel requirement for field operations per se with no-tillage as compared with clean or reduced tillage is offset to varying degrees by generally higher herbicide requirements and, in some cases, higher fertilizer requirements. The fuel requirements to produce maize under three tillage systems with constant and varying rates and forms of N fertilizer are summarized in Table 62 (Griffith and Parsons 1980). With constant N, the no-tillage system resulted in a 10 percent decrease in the fuel requirement, hut lower yields as compared with clean tillage. With the higher rate and different form of N, yields were similar, but the fuel requirement was 30 percent higher with no-tillage. These results indicate that all forms of N are not satisfactory for no-tillage systems.

The results in Table 62 also illustrate the decrease in fuel requirement with no-tillage for the manufacture and maintenance of machinery (tractors and equipment). Although not stated, these results imply that less equipment is required, that smaller tractors can be used, and that the equipment and tractors are used less frequently. The potential for lower equipment inventories and small tractors as well as less frequent use with no-tillage is also implied in Tables 57 to 61.

Data in Tables 57 to 62 and the related discussions were derived from and pertain to modern high-technology cropping (MHTC) systems, such as in the USA. Crop production operations in developing countries are accomplished mainly with hand labour, animals, or small tractors. Consequently, actual amounts of energy expended for different types of operations will vary widely from those reported above. However, relative differences among tillage systems (intensive, reduced or no-tillage) should follow the same trends as for the MHTC systems. For example, use of herbicides for weed control will decrease the need for tillage energy whether human, animal or tractor, regardless of cropping system. Where herbicides are not used, tillage or hand labour will be required. This may be an advantage where labour is plentiful. However, even under such conditions, some of the soil and water conservation benefits of reduced or no-tillage systems can be achieved if crop residues or weeds (after hoeing, cutting, etc.) are maintained on the soil surface as a mulch.

Although no-tillage systems have tremendous advantages over other systems with respect to soil and water conservation, usually an advantage with respect to labour, energy, and equipment savings, and sometimes an advantage with respect to crop yields, there are also some disadvantages associated with no-tillage systems. The disadvantages with respect to poorly-drained soils and in cool climates have already been discussed. Other disadvantages include increased use of chemicals, shift in weed populations, carry-over effect of herbicides, adverse effect of herbicides on adjacent crops, limited effectiveness of herbicides, limited water for spraying, high cost of herbicides, unavailability of suitable equipment (sprayers, planters), greater potential pest problems (insects, diseases, rodents), limited residues, soil compaction, and a need for greater managerial skills by the farm operator.

Al1 disadvantages listed do not apply to all situations. Neither are they listed in order of importance, nor is it possible to discuss them in detail in this report. However, some comments are made about each and pertinent literature, when available, is cited and can be consulted for additional information.

No-tillage systems are baser on the use of herbicides (chemicals) to control weeds. The greater use of herbicides with no-tillage as compared with other tillage systems is well known and has been shown in Tables 58, 61 and 62. More chemicals may also he used as insecticides and fertilizers (Tables 58 and 62; Harrison 1980; Kang et al 1980; Logan 1981; McDowell and McGreoonre1980; Phillips and Hendrix 1981; Thomas in press; and others).

Increased use of chemicals may add to production costs, which may make the use of no-tillage impractical for farmers with limited capital. In other cases, suitable chemicals may not be available. Where available and used, the greater usage has potential for increased pollution of ground or downstream water supplies. This may be a particular problem where readily soluble materials such as N fertilizers are used in large quantities and where P fertilizers and other chemicals are applied on the surface.

Less runoff from no-tillage usually results in lower chemical losses than from tilled areas (Baker and Johnson 1979; Logan 1981; McDowell and McGregor 1980; Thomas in press; Triplett et al. 1978). However, for materials such as N fertilizer, losses may be high due to increased percolation through the soil profile. Nitrogen losses can be reduced by making several small applications rather than one large application (Thomas in press).

Phosphorus losses with no-tillage are generally lower because of decreased losses of soil to which the P is adsorbed. However, McDowell and McGregor (1980) reported greater P concentrations in solution and losses in runoff with no-tillage than with clean tillage. The greater losses were attributed to insufficient sediment to adsorb the P from solution, greater application rates, decreased incorporation, release of P from residues, and possibly greater P-supplying capacity of sediments in runoff from no-tillage areas.

Losses of herbicides and insecticides from no-tillage areas were strongly influenced by application rates and length of intervals between application and runoff event (Baker and Johnson 1979; Edwards et al. 1980; Logan 1981; Triplett et al. 1978). Losses were greatest when the chemicals were applied at high rates and when runoff occurred relatively soon after application of the chemicals.

Herbicides are relied upon for controlling weeds in no-tillage systems. The mode of action of herbicides and the type of weeds to be controlled largely influence which herbicides can be used in a particular cropping system. To avoid crop damage, herbicides must be compatible with present and future crops.

Compatibility of herbicides with crops is of major concern where several crops are grown on small areas by intercropping, mixed cropping, relay cropping, etc. Unless compatible with all crops, weed control with herbicides may not be possible because of potential damage to crops. On larger areas, compatibility with adjacent crops must still be considered because of the hazard from drifting spray.

Compatibility with subsequent crops to be grown on a given tract of land is of concern where herbicides are used that have a residual effect. Depending on the herbicide used, susceptible crops may need to be avoided until the herbicide has been sufficiently; degraded. Factors influencing the fate of herbicides include detoxication, photodecomposition, absorption and exudation, volatinization, chemical decomposition, adsorption, biological degradation, crop removal, runoff, leaching, and capillary flow (S-18 Tech. Comm. 1972). Some specific soil factors involved in these prcocesses include soil organic matter, chemical, and water content (S-l8 Tech. Comm. 1972); soil pH (With 1980[?)); soil texture (sandj, silt and clay content) and profile characteristics; and the frequency and distribution of precipitation (Baker and Johnson 1979; Edwards et al. 1980; Logan 1981; Triplett et al . 1978) .

Most herbicides are intended to control specific weeds or groups of closely related weeds, and excellent control may he achieved. However, shifts in weed populations have resulted from use of herbicides in no-tillage systems when applied herbicides did not control all species of weeds that were present (Phillips 1969; Rickey et al. 1977; Wiese and Staniforth 1973). For example, the weed population in a wheat-fallow-sorghum rotation in Kansas (USA) shifted from broadleaf species susceptible to atrazine to sandbur, which was resistant. Consequently, yields were decreased unless sandbur was controlled with tillage. The herbicide-tillage combination resulted in yields of 3 700 kg/ha compared with 2 400 kg/ha with herbicides alone (Phillips 1969).

Application of adapted herbicides normally results in effective control of susceptible weeds; however, even adapted herbicides sometimes fail to achieve desirable levels of control. In other cases, the best available herbicides have limited effectiveness against troublesome weeds. Under such conditions, the no-tillage system has a serious handicap because other means of weed control, such as by tillage or hoeing, are difficult and ineffective due to the surface residues and a firm soil. Development of improved herbicides will minimize the problem (Richey et al. 1977). Where troublesome weeds are present or expected to be a problem, no-tillage is not recommended, herbicide-tillage combinations should be used, or crops should be rotated so that a more effective herbicide can be applied (Fig. 89).

Fig. 89

Some grassy weeds are not controlled by herbicides in a no-tillage system involving wheat and sorghum. Where such weed problems are severe, a limited tillage system may be more appropriate

A major limitation to widespread use of no-tillage systems is the high cost of herbicides, especially in developing countries. Where weeds can be effectively controlled with one or two applications of relatively inexpensive herbicides, the no-tillage system is often as economical or more economical than tillage systems (see Section 3.3). Where such contact herbicides as paraquat and glyphosate, which are quite expensive, are required, production costs greatly increase, especially in humid tropical locations where weed problems persist throughout the year and several applications of herbicides are required. However, weed control by other means is also difficult under such conditions. Therefore, the final decision on type of tillage system to be used under such conditions will depend on the relative production cost with herbicides, tillage, or hand labour.

A disadvantage of no-tillage systems that is most serious for small-scale operators in developing countries is the remote and sometimes limited supply of water for diluting the herbicides for effective application. Some herbicides are translocated throughout the plant or absorbed from soil and, therefore, do not require too much water as a carrier for satisfactory dilution and application. Other herbicides, however, must thoroughly cover the weeds or soil, thus requiring a relatively large amount of water for dilution and application, especially when large quantities of crop residues are present on the soil surface.

The amount of water required varies from about 47 to 187 litres/ha (5 to 20 gallons/acre), depending on the herbicide used (A.F. Wiese, Bushland,Texas, personal communication). Amounts as low as 5 litres/ha, or less, were adequate when a tractor-mounted controlled droplet applicator (CDA) was used (Taylor et aZ. 1976). Handcarried CDA equipment is also available (Wiese, in press.). The actual quantity needed for a particular herbicide is given on the product label and should be closely followed for most effective weed control.

The indicated amounts of water are no major problem where it is plentiful and can be readily transported to the field. However, where water is limited, remotely located with respect to the area to be sprayed, and must be transported by humans or animals along trails, even the low amount may present a problem and, therefore, discourage the use of herbicides for controlling weeds.

A final disadvantage of no-tillage with respect to use of herbicides in developing countries is the limited availability of suitable equipment for applying herbicides. Several types of sprayers for use on small areas are available (Wijewardene, n.d.). These include a knapsack and an atomizer-disk sprayer, each capable of spraying a 1 m wide swath and using only about 40 litres of spray material per hectare (Wijewardene, n.d.). However, even such sprayers may cost more than a farmer in a developing country can afford. Satisfactory sprayers are available in developed countries.

Another tool needed by the no-tillage farmer is a planter capable of placing seed in residue-covered soil. Many equipment manufacturers have developed no-tillage planters, mainly for relatively large-scale farming operations. These planters normally have a coulter or knife to cut the residues, a device to open a slot for the seed, a seed covering device and a press wheel (Figs. 90, 91). For satisfactory operation and penetration in undisturbed soil, the units are heavily constructed or built to receive add-on weight, often up to about 275 kg for each planter. Such units are practical where large tractors are used and usually result in satisfactory crop establishment. However, problems sometimes arise from non-

Fig. 90 Rippled coulter ahead of unit planter that can be used for no-tillage seeding of a crop

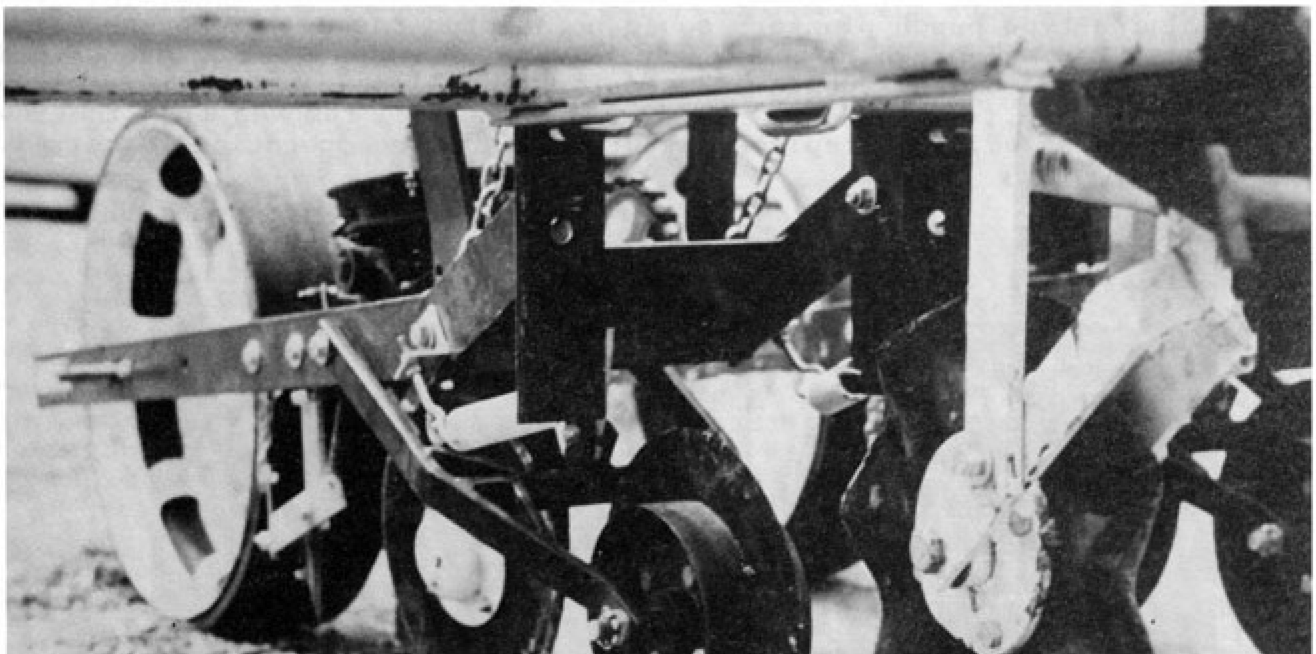


Fig. 91 Unit planter with fluted coulter, straight coulter with bands to control depth, double disk opener for placing seed, and press wheel. Such planters can be used for no-tillage seeding of a crop

uniform emergence of seedlings resulting from improper seed placement, inadequate soil cover cover the seed and poor preparation of the seed zone by the no-tillage planter. Another problem that can be encountered is poor penetration of the soil because of excessive amounts of surface residues or a hard, dry soil surface (Smith l98[?]).

The heavy-duty planters described above are not adaptable to sma11 farms where humans, animals or small tractors provide the power for the planting operation. Smaller or lighter versions o no-tillage planters could be usec9 with small tractors or even with animals on relatively small farms, provided that surface residues and hard, dry soil surfaces do not interfere with the planting. Such plantors, however, may be ton expensive for the small-scale farmer.

The small-scale farmer relying on hand labour can use planting methods for no-tillage similar to those where tillage has been performed. The simplest way is to make a hole with a pointed stick, hoe, machette or other tool, put in the seed and cover it with snil. Such planting is essentially the same as the. peoples of Africa and Asia have used for a long time, mainly to save labour within the range of facilities and tools available to them (Constantinesco 1976).

Several types of punch planters have been developed for or are adaptable to no-tillage planting. Single hole, multiple hole and rolling types for one or more rows are available (Hopfen 1969; Wijewardene, n.d.). Although designed for hand use, the multiple row rolling-type punch planters could be adapted for pulling by animals. Other animal-drawn planters that were designed for clean-tilled areas (Hopfen 1969) could be used for no-tillage planting if residue amounts are relatively low or the residues are removed from the row to be planted, then replaced after the planting operation (Figs. 63, 92),

Fig. 92 Crop seeding in India (photo provided by B.A. Stewart, USDA-ARS)

Broadcast or surface planting is usually a less satisfactory method of planting than that of placing seeds in soil. However, crops such as wheat, oats, etc. have been overseeded into another crop approaching maturity. For example., wheat was successfully surface planted in soybeans, with the: latter's fallen leaves provirding a moist soil surface for satisfactory wheat germination and seedling establishment (Sandford et al. 1974).

The potential for greater insect and disease problems with no-tillage than with clean tillage has been recognized and widely discussed. However, no major differences in the problems have been encountered. Some insect and disease problems are more severe with no-tillage, others with clean tillage. The effect of tillage method on insect and disease as well as rodent and other animal problems was discussed in Section 3.2.4.ii.d. The disadvantages of no-tillage with respect to these problems are essentially the advantages of clean tillage.

A major deterrent to successful implementation of a no-tillage cropping system in many developing countries is the limited amount of residues available for management on the soil surface for water conservation and erosion control. Residues may he limited because of low amounts produced, high decomposition rates (under hot, humid conditions), removal for other purposes, burning, or destruction by insects, mainly termites (Lal 1975; C.S. Ofori, FAO, Rome, personal communication; Okigbo and Lal 1977). Where the soil has become eroded and degraded, a no-tillage system will not be satisfactory (Charreau 1977; Lal 1980, 1980[?]). To reclaim such soils, suitable cover crops should be grown for several years to help improve soil structure and water infiltration rate before initiating a no-tillage system (Lal 1980[?]). On non-degraded soils that produce residues at present, these should not be removed or burned when a nn-tillage system is to be initiated.

One reason frequently given for tillage is that it loosens the soil and improves its tilth. Therefore, by inference, no-tillage should be detrimental to good tilth, result in a dense soil, and consequently reduce water infiltration and crop yields. This, however, has not generally occurred as determined from water infiltration measurements (Tables 8, 12, 31, 32, 43 and 46) and crop yields (Tables 33, 34, 37 and 44). Where yield decreases occurred with no-tillage (Tables 33, 34, 36 and 38), they usually resulted from poor weed control, poorly drained soils or lower soil temperatures. Except for the surface layer, soil bulk densities have been no greater on no-tillage than on tilled areas.

In central Kentucky, bulk densities were not significantly different in conventional and no-tillage areas after 10 years of cropping to maize. In western Kentucky, soil for soybeans was slightly less dense where it was chiselled than where it was ploughed or not ploughed (no-tillage) for which the densities were identical. Chiselling also resulted in slightly lower bulk density than ploughing or no-tillage in Indiana, with differences for the latter two treatments differing by only 0.04 g/cm , Bulk densities were 1.43 and 1.48 g/cm with tillage and no-tillage, respectively, in Virginia. First year results for a study in Argentina indicated that bulk densities were 0.21 g/cm higher with no-tillage than with conventional (clean) tillage. However, after 4 years, the differences were slight and had no effect on yields (Thomas in press).

In the tenth year of a tillage study for maize in Minnesota, bulk densities in traffic and no-traffic zones were 0.20 and 0.25 g/cm higher, respectively, with no-tillage than with an autumn ploughing plus spring cultivation treatment (Lindstrom et al. 1981). However, spring cultivation was performed 4 days before measuring densities whereas no-tillage plots had been undisturbed for about 10 years.

Soil compaction, mainly in the surface layer, may become a problem in no-tillage fields due to trampling by animals where the crop is harvested by grazing or where animals are permitted to forage on the land after crop harvest. Compaction may also occur during harvest due to tractor, equipment, animal or human traffic. Where compaction is a problem, an operation with a sweep or chisel implement should loosen the soil adequately to permit planting of the next crop. Such operation should be performed as long as possible before planting so that natural weathering will additionally loosen the soil. One operation with a chisel plough, and especially a sweep plough, incorporates only a small amount of surface residues (Table 22) and consequently has little effect on soil and water conservation as compared with no-tillage (Unger 1977; Unger et al. 1971).

No-tillage crop production, as a rule, requires a higher level of management than that for crop production by conventional or traditional methods. This requirement may thus be a disadvantage of the no-tillage system. Whereas most farmers have gained considerable knowledge and skills for crop production by conventional or traditional methods, experiences regarding the no-tillage system are limited because it is relatively new. Therefore, farmers without experience who plan to adopt the no-tillage system should try it on a limited basis to gain experience before devoting all resources to this farming technique. The producer must know how a piece of equipment will function in a given situation, what herbicides are available to control a particular weed or volunteer crop, what effect herbicides will have on subsequent crops, what can be done if they are not effective, and what can be done if insect and disease problems become severe. Interested producers must be willing, or be given an incentive, to assume the risks to gain the necessary experience, because the no-tillage system has tremendous benefits with respect to soil and water conservation.

3.2.5 Dust Mulches

Dust mulches (also called soil mulches) have been researched and discussed for many years as a potential means of conserving water. Although, under field conditions, they were shown to be relatively ineffective for conserving water by the early 1900s, as indicated by a brief review by James (1945), they continue to be studied and have been shown to be effective for water conservation on some soils and under some environmental conditions. Consequently, it is deemed appropriate to devote a short section of this report to a discussion of dust mulches with respect to conditions under which they may or may not be effective.

Dust mulching is essentially a clean-tillage system that could be used in any of the major cultivation systems. It consists of loose, finely granular or powdery soil at the soil surface and is usually produced by shallow tillage or cultivation.

Differing results with soil mulches were reported by Benoit and Kirkham (1963) and Hanks and Woodruff (1958) for studies conducted in the laboratory. In the former study, dry soil, gravel or maize cob mulches were placed on the surface of previously wetted soil. Each mulching material reduced water loss compared with an unmulched soil, but the soil mulch was the least effective. Some water moved into the dry soil mulch by capillary action, which contributed to higher evaporative losses with this treatment.

Water movement into the gravel and maize cob mulches was slight. The rate of water loss increased with increases in radiation and air movement. Unmulched cores lost 1.25 to 5 times more water than mulched cores by the end of 600 hours.

A soil mulch was more effective than gravel and straw mulches in the study by Hanks and Woodruff (1958). However, in this study, the mulches were separated by screens from the saturated soil beneath and water losses occurred in the vapour phase (no capillary movement of water toward the surface). As wind speeds increased, evaporation increased also, but the increase was greater with gravel and straw mulches than with the soil mulch. The greater water losses with gravel and straw mulches resulted from greater vapour conductivity through the larger pores of these mulches than through the smaller pores of the soil mulch. The soil mulch had a 1.45 g/cm bulk density.

In a laboratory study by Gill et al. (1977), previously saturated and drained columns of a silty clay loam soil were stirred (tilled) to a 5 cm depth at four times when the water content to that depth ranged between 34 and 11 percent by volume. A sandy loam soil was similarly treated at water contents between 25 and 9 percent. Different tilth levels (coarse, medium, fine and very fine) were achieved by differential stirring of the soils. Under low evaporativity, tillage at all times significantly reduced water losses from both soils as compared with the losses from untilled soils. Tillage at the first three times was equally effective and conserved more water than the fourth tillage in the silty clay loam. In the sandy loam, tillage at the first two times was most effective. Under high evaporativity, the first time of tillage of the sandy loam and the second time of the silty clay loam were more effective for water conservation than other times of tillage. The effect of tilth varied with time of tillage and evaporativity. Less water was conserved with the coarse tilth than with others regardless of soil and time of tillage under low evaporativity. Under high evaporativity, coarse and medium tilths were more effective with early tillage, and finer tilths were more effective with subsequent times of tillage. The mean weight diameters of clods, averaged for both soils, were 46, 14, 10 and 4 mm for the coarse, medium, fine and very fine tilths, respectively. Most tilths were slightly lower for the sandy loam than for the silty clay loam soil.

The foregoing laboratory studies illustrated the effects of soil and other mulches for conserving water already in a soil, namely by reducing evaporation. However, under field conditions, water conservation entails not only evaporation reduction, but also water infiltration into a soil. Consequently, effects of dust (or soil) mulches in the field varied widely, depending on conditions under which they were evaluated.

In general, water conservation with a dust mulch was higher than with a bare, untilled soil, but not necessarily higher than with other mulches where the soil water content was high initially, as at the end of the rainy season, or where water moved toward the surface from deeper soil layers (Ali 1976; Bolton and De Datta 1979; De Datta 1978; Hundal and De Datta 1982; Jalota and Prihar 1979; Papendick et al. 1973; Papendick and Miller 1977; Sachan 1976). Dust mulches were usually ineffective for conserving water where precipitation occurred mainly during summer when the potential for evaporation was highest (Call and Sewell 1917; Jacks et al. 1955; James 1945; McCall 1925; Shaw 1929) because much of the water was lost by the time tillage could be performed to establish the mulch. In addition to the general ineffectiveness of a dust mulch, as in the Great Plains (USA), frequent cultivation was necessary to keep the mulch intact and the resultant bare soil was highly susceptible to erosion (Jacks et al. 1955). Water was conserved with a dust mulch where rainfall thoroughly wet the soil profile and the mulch was reestablished before major loss of the water occurred (Jalota and Prihar 1979).

3.3 C0ST COMPARISON5 OF TILLAGE SYSTEM

Primary goals of subsistence farmers are to provide an adequate and reliable source of food for themselves and their families. Monetary goals are secondary in nature, but increase in importance after the primary goals are achieved and if suitable markets arc available for crop products in excess of the farmer's basic needs.

In market-oriented crop production systems, traditionally farmers have been interested in using those tillage systems that improve farm profits. Unfortunately, the effect of production methods on soil erosion and land degradation has been ignored in many cases. However, current concern about land degradation throughout the world and about soil erosion in particular has focused major attention on the economics of crop production involving tillage systems that have the potential for greatly reducing soil erosion.

In foregoing sections, data were presented and discussed which showed that minimum or reduced and especially no-tillage cropping systems greatly reduced soil erosion as compared with clean tillage methods. If these systems are to be widely promoted and adopted for erosion control, they must be economically equal or superior to existing ones. An economic benefit may be sufficient incentive for many farmers to adopt these conservation measures without being required to do so because of governmental regulations (Forster et al. 1976).

A new or different cropping system must be less expensive and more efficient to have an economic advantage over an existing one. A new system is less expensive if less labour, fuel and capital are required. A system is more efficient if it increases the quantity and improves the quality of products to be used or sold in relation to the cost of production. Because of highly variable and rapidly changing production costs and product prices in different countries, assigning monetary values to different tillage systems has little meaning. Therefore, the major emphasis in this section is on identifying and discussing the factors that affect expenses and income. However, some examples are given to illustrate the effects of different tillage systems on production costs and income. For other situations, prevailing prices and alternate operations can be substituted for those given in the examples to obtain a more realistic economic analysis of different systems.

Labour and equipment (tractor, ploughs, fuel, etc.) expenses for crop production can be reduced by eliminating field operations, reducing the number of time-intensive operations, or by using larger equipment (mainly for labour savings). Major advantages of minimum and no-tillage systems from an economic viewpoint are the lower labour and equipment requirements because intensive tillage such as mouldboard ploughing is usually not done and because two or more other operations can usually be eliminated by using these systems as compared with clean tillage. Part of the savings, however, may be offset by higher expenses for herbicides.

The labour and equipment requirements per unit area are greatly influenced by the type of tillage or crop production operation performed when tractor size remains constant. As tillage depth and intensity increase, time required to perform the operation increases. When factors such as soil type and water content remain unchanged, time required to perform different operations is related to the amount of fuel expended. Some values for different operations are given in Table 24 (Allen 1977). Some differences were related to depth of tillage, but mouldboard ploughing required the most fuel and was followed in order by chiselling, disking and sweep ploughing. Different values would be obtained for other soils, ploughing depths and soil water contents, but for all conditions, eliminating fuel-intensive operations reduces the labour and equipment requirement for tillage (Unger and McCalla 1980).

A further saving in labour is possible by using larger equipment. However, larger equipment is more expensive initially and may require greater skill to operate. Thus, if larger equipment is being considered, all advantages (labour savings, timeliness of operations, etc.) must be weighed against possible disadvantages (higher costs, higher skilled labour requirement, alternate use of unused labour, lower suitability for use with soil conservation measures, etc.).

When production expenses remain constant, crop values must be increased to obtain higher returns from a new or different crop production system. Because of higher yields, stubble mulch tillage was more economical than one-way disk tillage for wheat production in Texas (USA), even though fuel use was similar for both systems (Allen and Fryrear 1980). When production expenses are decreased and yields are increased, remain unchanged, or even decreased slightly, reduced-tillage systems are more economical than tillage-intensive systems. With irrigation, additional benefits from reduced-tillage systems may result from greater water conservation, which results in lower expenses for irrigation (Allen and Fryrear 1980) to produce equal yield.

Some examples of costs of performing various crop production operations are shown in Table 63. The costs are based on the most common amount charged by custom operators (for hire) in Texas (USA) in 1981 (Murfield et al. 1981), and are probably different from the actual costs of operation if the farmer owns the equipment. Costs of harvesting and hauling are not included because they would be the same regardless of tillage system, except possibly some adjustments for different yield levels. Herbicide and fertilizer costs are not included because they would differ for different soils, crops and management systems. The charges would also vary for dryland and irrigated crops. The values given in Table 63 are intended only as a guide and differ from those reported for other locations or situations. The comparisons of tillage systems in the following paragraphs are based on values given in the different reports, not those given in Table 63, and represent data for a variety of cropping systems.

Data in Table 64 are for cropping systems adaptable and widely used in the semi-arid southern Great Plains (USA). All except the double cropping system are also adaptable to most other portions of the semi-arid to subhumid Great Plains. For all sequences, limited or no-tillage systems resulted in lower total expenses than clean tillage. Overall economics usually favoured the limited or no-tillage systems because of higher average yields (Allen et al. 1975, 1976, 1980; Musick et al. 1977; Unger and Wiese 1979). Continuous no-tillage generally was not practical for wheat to wheat and sorghum to sorghum sequences, mainly because of difficulty and added expenses for controlling volunteer crop plants (Allen et al. 1976; Unger 1977).

Data in Table 65 illustrate that minimum and no-tillage result in lower expenses than clean tillage, mainly because the expensive ploughing and disking operations are eliminated. For minimum tillage, however, three tine cultivations are required which offset some of the savings. No-tillage with farmer-owned drills resulted in lower expenses than when the drilling was contracted (ICI Plant Protection 1976). Average yields were not given, but farmers expressed general satisfaction with the minimum and no-tillage systems for various crops.

A comparison of no-tillage and clean tillage for maize and soybeans in Tennessee (USA), which is in a subhimid to humid region, is given in Table 66. Reduced expenses with no-tillage resulted from lower labour and machinery (variable and fixed) costs. Although part of the savings was offset by greater expenses for seed and chemicals, no-tillage systems still resulted in lower total expenses and greater net returns than clean tillage because estimated yields were the same for both systems (Hudson E.H. 1981).

Table 63 CUSTOM (FOR HIRE) RATES FOR CROP PRODUCTION OPERATIONS IN TEXAS (USA), 1981 (from Murfield et al. 1981)

Operations		Cost/ha $
Tillage		
Mouldboard		24.70
One-way disk		12.40
Offset disk		14.80
Tandem disk:	Light weight	9.90
	Medium weight	12.40
	Heavy weight	14.80
Chisel:	Surface layer (7-20 cm)	12.40
	Deep	24.70
Harrow:	Spike tooth	7.40
	Spring tooth	9.90
Field cultivate - sweeps		12.40
Lister		9.90
Shaping beds:	Row disk	9.90
	Rolling cultivator	9.90
	Sweep cultivator	9.90
Rolling cultivator:	Flat tillage	9.90
Sand fighter		4.90
Rodweeder		9.90
Rotary hoe		7.40
Row crop cultivating		9.90
Land levelling - float		12.40
Fertilizer and lime application		
Anhydrous ammonia		9.90
Dry mixed fertilizer		4.90
Liquid fertilizer		4.90
Lime		4.90
Chemical application - flat rate		
Aerial:	Insecticide & fungicide	6.20
	Herbicide	6.20
Ground:	Insecticide & fungicide	4.90
	Herbicide	4.90
Planting		
Row crops		12.40
Drilled crops		9.90
Sod drilling small grains		7.40
Stalk shredding		7.40

Table 64 COST OF TILLAGE AND HERBICIDES FOR VARIOUS CROPPING SEQUENCES WITH SURFACE IRRIGATION ON THE SOUTHERN GREAT PLAINS (USA) (from Wiese *et al.* 1979)

Cropping sequence	Operations and total expenses	
	Clean tillage	Limited or no-tillage
Wheat to sorghum, double-cropped	Disk, disk, bed, apply atrazine (1.8 kg/ha) $52/ha	Apply atrazine (1.8 kg/ha) $17/ha
Wheat to wheat	Disk, disk, bed, cultivate $44/ha	Disk-bed, cultivate $26/ha
Sorghum to sorghum	Disk, disk, chisel, bed, cultivate $49/ha	Shred, split beds, cultivate $30/ha
Wheat-fallow-sorghum[1]	Disk, disk, disk, bed, cultivate, cultivate $44/ha	Apply atrazine (3.4 kg/ha) and 2,4-D (1.1 kg/ha) $30/ha

[1] Operations and expenses are for the wheat to sorghum phase of the rotation. For sorghum to wheat, the area was uniformly tilled.

Table 65 BRITISH NATIONAL AVERAGE EXPENSES FOR ESTABLISHING A CEREAL CROP IN STUBBLE (from ICI - Plant Protection 1976)

Operation or expense	Operations or expense items			Expenses			
	Conventional tillage	Minimum tillage	No-tillage	Conventional tillage	Minimum tillage	No-tillage[1]	No-tillage[2]
	-------- No. ----------			---------- UK £/hectare ---------			
Ploughing	1	-	-	16.70	-	-	-
Disking	2	-	-	12.80	-	-	-
Herbicide (litres)	1.2	1.2	2.4	4.60	4.60	9.20	9.20
Herbicide application	1	1	1	3.70	3.70	3.70	3.70
Harrowing	1	1	1	4.00	4.00	4.00	4.00
Tine cultivation	-	3	-	-	21.00	-	-
Seeding	1	1	1	8.20	8.20	14.20	9.40
Totals				50.00	41.50	31.10	26.30

[1] Seeding was contracted (hired).

[2] Seeding with farmer's own drill.

Table 66 ESTIMATED COST OF CONVENTIONAL (CLEAN) AND NO-TILLAGE SYSTEMS FOR MAIZE AND SOYBEAN IN TENNESSEE (USA) IN DECEMBER 1980[1] (from Hudson E.H. 1981)

Item	Maize		Soybeans	
	No-tillage	Conv. tillage	No-tillage	Conv. tillage
	US$/hectare			
Seed	28.40	24.70	25.60	17.20
Fertilizer and lime	117.40	117.10	58.00	58.00
Chemicals	69.20	47.30	78.60	58.00
Machinery (variable cost)	30.10	61.90	36.20	70.30
Labour	12.10	25.10	13.00	25.90
Total variable cost	257.20	276.10	211.40	229.40
Machinery (fixed cost)	36.50	60.60	39.10	61.60
Total cost	293.70	336.70	250.50	292.00

[1] Land and interest expenses are not included.

According to the same author, the comparison of no and conventional tillage answers only a part of the economic question. A complete farm plan is required to answer the ultimate question of whether no-tillage has a place on a given farm. The analysis by Brown and White (1973) considers the impact of seven tillage-planting systems on maize, soybean and hog production on a 243 ha (600 acre) farm in Indiana (USA), which is in a humid region. The results are summarized in Table 67.

Average maize and soybean yields differed only slightly for the various systems. However, most reduced and the no-tillage systems permitted larger areas of maize production because larger areas could be planted at or near the optimum time without the usual risk of lower yields at a sub-optimum planting date. Larger maize areas with resultant higher total maize yields permitted feeding of pigs on the farm rather than selling them. Feeding the pigs was also made possible by the lower labour requirement for cultural operations. These differences, coupled with a lower total investment resulted in no-tillage having the highest net profit and return on the investment. The increase with no-tillage over the till-plant system, however, was slight. The wheel track planting system was least profitable because it permitted only a small area of maize due to major tillage and planting being required in a short period. This analysis showed that in order to obtain the total benefits from shifting to reduced or no-tillage cropping systems, the farmer must change the overall farming operation at the same time as changing the tillage system (Brown and White 1973).

An example of shifts in the farm enterprise when a direct drilling (no-tillage) system is used was reported by Patterson (1980). The example (Table 68) is based on a 1000 ha farm in Australia. Use of direct drilling increased the annually cultivated area and the number of sheep on the grazed area, which resulted in almost a $A 16 000 increase in profits.

The effect of tillage system and soil type on the economics of maize and soybean production in Ohio (USA), also in a humid region, is illustrated in Table 69 (Forster et al. 1976). The reduced tillage systems (minimum and no-tillage) were more profitable than conventional tillage on Wooster, Rossmoyne and Crosby soils, which are well, moderately well and somewhat poorly drained, respectively. The 100% maize system was more profitable than the 50% maize-50% soybean system. Because of major yield

Table 67 INCOME, AVERAGE CROP YIELDS, AND FARM ORGANIZATION FROM SEVEN TILLAGE-PLANTING SYSTEMS IN INDIANA (USA) (from Brown and White 1973)

Item	Tillage-planting system						
	Conventional	Field Cult.	Wheel Track	Chisel	Strip Rotary	Till Plant	No Till
Gross profit	$ 58 538	$ 62 835	$ 57 869	$ 62 188	$ 62 559	$ 64 283	$ 64 098
Fixed cost	15 262	15 699	15 487	15 548	15 759	15 358	15 069
Net profit (return to land, labour, and capital)	43 276	47 136	42 382	46 640	46 800	48 925	49 029
Labour charge	14 000	14 000	14 000	14 000	14 000	14 000	14 000
Returns to land and capital	29 276	33 136	28 382	32 640	32 800	34 925	35 029
Investment: Land	420 000	420 000	420 000	420 000	420 000	420 000	420 000
Capital	58 421	60 429	59 886	60 001	61 886	58 890	57 477
Total	478 421	480 429	479 886	480 001	481 886	478 890	477 477
Return on investment (%)	6.12	6.90	5.91	6.80	6.81	7.29	7.34
Maize area (ha)	154	162	80	169	178	200	208
Soybean area (ha)	89	81	163	74	65	43	35
Total land used (ha)	243	243	243	243	243	243	243
Land in maize (%)	63.3	66.5	33.3	69.5	73.3	82.3	85.5
Average maize yield (kg/ha)	9 020	9 080	9 050	9 040	9 010	9 010	8 990
Average soybean yield (kg/ha)	2 770	2 820	2 750	2 820	2 820	282	2 820
Number of sows	75	75	75	75	75	75	75
Number of pigs fed out	794	1 423	1 423	1 423	1 423	1 423	1 423
Number of feeder pigs sold	629	0	0	0	0	0	0

Table 68 EFFECT OF TILLAGE SYSTEM ON CROP AND SHEEP PRODUCTION ON A 1000 HEC TARE FARM IN AUSTRALIA (from Patterson 1980)

Factor	Tillage method	
	Conventional	Direct-drill
Area cropped annually (ha)	250	300
Area available for grazing (ha)	750	700
Stocking rate (ewes/ha)	3	3.5
Total carrying capacity (ewes)	2 250	2 450
Gross return from crops ($A)	44 438	55 620
Gross return from sheep ($A)	54 000	58 800
Total gross return ($A)	98 438	114 420

reductions associated with late maize planting, intensive maize production favours the time-saving reduced tillage systems. On the flat, fine-textured, poorly-drained Brookston and Hoytville soils, profits were reduced by minimum and no-tillage as compared with conventional tillage. On such soils, reduced tillage systems in general are not practical and may not be needed because erosion is light. In addition, farmers will probably not accept minimum and especially no-tillage systems on such soils, because of lower profits, unless erosion is significant and they are required to use such systems. Additional research is needed with reduced tillage systems on such soils to improve yields and raise profits to levels comparable to those with conventional tillage (Forster et al. 1976). If profits cannot be increased and farmers are still required to use reduced tillage to minimize erosion, then they should be compensated for using the systems. Society as a whole benefits from erosion control and, therefore should accept part of the financial responsibility for implementing control measures.

Data in Table 70 are for a 3 year rotation (two crops in 3 years) in a semi-arid area in Washington (USA) where annual soil losses are estimated to be about 45 tons/ha (Hinman et al. 1981a). For the conventional system, a mouldboard plough and flex harrow (flexible frame, spike tooth) were used for major tillage whereas a chisel was the main tillage implement in the conservation tillage system. Substituting chiselling for mouldboard ploughing and flex harrowing was the major reason for lower expenses for barley and fallow with conservation tillage (Table 70). The increase in expenses for wheat with conservation tillage resulted mainly from greater costs for rodweeding and drilling. Overall, conservation tillage resulted in about $14/ha (one-third of net return shown in Table 70) greater returns annually than conventional tillage.

The representative data presented in Tables 64 to 70 indicate that reduced tillage systems, not necessarily no-tillage, can be as or more economical than conventional or clean tillage systems. Similar results have been reported also by Engle and Florea (1979), Hemmer and Forster (1981), Hinman et al. (1981b), Mohasci and Hinman (1981), Scherp (1979), and Taylor et al. (1980). Reduced tillage systems sometimes were less economical on poorly drained soils (Forster et al. 1976), where ploughing and planting (wheel track planting) in a short period limited the area planted to maize (Brown and White 1973), where weeds and volunteer crop plants were major problems (Allen et al. 1980; Unger 1977), and where reduced (no-) tillage required more and a different form of N fertilizer (Griffith and Parsons 1980). The reduced tillage systems could also be less economical in some developing countries where relative costs of labour, equipment and

Table 69 EFFECT OF TILLAGE SYSTEM AND SOIL TYPE ON THE ECONOMICS OF MAIZE AND SOYBEAN PRODUCTION IN OHIO (USA) (from Forster *et al.* 1976)

Tillage system and soil type	Variable cost		Total cost[1]		Yields[2]			Total profit[3]	
	Maize	Soybean	100% maize	50% maize + 50% soybean	100% maize	50% each Maize	50% each Soybean	100% maize	50% maize + 50% soybean
	US$/ha				kg/ha			US$/ha	
Conventional									
Wooster	326	184	616	545	7 090	7 400	2 260	82	64
Rossmoyne	328	184	618	546	7 460	7 840	2 380	117	98
Crosby	326	184	616	545	7 210	7 530	2 260	94	70
Brookston	337	184	627	551	8 470	8 970	2 700	207	183
Hoytville	314	184	604	539	7 151	7 400	2 010	100	43
Minimum									
Rossmoyne	328	186	611	540	7 340	7 650	2 380	112	95
Crosby	329	186	612	541	7 650	7 900	2 320	142	100
Brookston	337	186	620	545	8 090	8 400	2 570	177	148
No-tillage									
Wooster	325	185	607	538	7 970	8 280	2 070	178	95
Rossmoyne	325	185	607	538	7 651	7 970	2 380	147	114
Crosby	324	185	606	537	7 590	7 840	2 320	142	101
Brookston	332	185	614	541	7 780	8 090	2 450	152	123
Hoytville	308	185	590	529	6 020	6 270	1 820	4	-22

[1] Includes fixed costs of $290, $283 and $282 for conventional, minimum and no-tillage, respectively. The fixed costs include a $198/ha charge for land.

[2] Higher yields for the 50% maize cropping pattern reflect earlier average planting of the smaller maize area.

[3] Based on a maize price of $9.83/100 kg and a soybean price of $21.62/100 kg.

herbicides are different and where labour is abundant. A valid cost comparison for different tillage systems can be obtained only by an analysis based on conditions that prevail at a given location.

Table 70 ESTIMATED RECEIPTS AND EXPENSES FOR A SPRING BARLEY-FALLOW-WINTER WHEAT (3 YEAR) ROTATION IN WHITMAN COUNTY, WASHINGTON (USA), WITH CONVENTIONAL AND CONSERVATION TILLAGE (from Hinman et al. 1981)

Item	Tillage system	
	Conventional	Conservation
	US$/3 ha [1]	
Receipts		
Barley (3 360 kg/ha)	418.83	418.83
Wheat (3 700 kg/ha)	577.60	577.60
Total receipts	996.43	996.43
Expenses		
Barley		
Machine and labour[2]	192.42	163.14
Input and service[3]	105.56	105.56
Other (overhead, interest, taxes, insurance)	27.63	26.14
Summer fallow		
Machine and labour[2]	93.53	76.77
Input and service [3]	72.80	72.80
Other (overhead, interest, taxes)	17.22	16.65
Wheat		
Machine and labour[2]	114.53	122.34
Input and service[3]	72.85	72.85
Other (overhead, interest, taxes, insurance)	46.16	44.06
Total expenses	742.70	700.31
Net returns	253.73	296.12

1 Values are the total for 3 ha because each phase of the rotation occurs on 1 ha only once in 3 years.
2 Includes tillage, fertilizer and herbicide application, harvesting and grain hauling.
3 Includes costs of fertilizers, herbicides, aerial spraying, and/or seed.

4. CROP MANAGEMENT SYSTEMS IN RELATION T0 TILLAGE

The conservation of soil and water resources, in addition to tillage systems, is affected by the overall crop management systems in which the tillage systems are used. Crop management embraces several topics including management of planting materials, management of land before planting, seedbed preparation, planting, soil management, management of plant pests, and management of plant products (Sprague 1979). A subtopic related to several of these is cropping systems or sequences. This subtopic, which has a direct influence on soil and water conservation, will receive the major emphasis in this consideration of crop management. The discussion of cropping systems or sequences will involve continuous (or annual) cropping, crop rotations and multiple cropping (which includes intercropping and sequential cropping).

4.1 CONTINUOUS CROPPING

Continuous (or annual) cropping for this report involves the production of a given crop on the same land each year. The growing season for the crop may be entirely within a year (e.g. maize, cotton, spring wheat, etc.), within parts of two years (e.g. winter wheat, other winter crops), or cover several years (e.g. sugarcane, some forage crops, tree crops). In regions where conditions for crop growth. are sufficiently long, two or more crops may be grown on the same land each year. Although the emphasis is on the same crop each year, this restriction does not preclude the use of a cover crop, provided the main crop is still grown during the appropriate growing season. It also does not preclude the production of two or more crops by the same farmer, provided each crop is grown on its own area each year.

Probably the greatest advantage of continuous cropping is the potential for obtaining the greatest production of the most desirable crops. For a given locale, one or a few crops are usually most desirable because of yield levels, ease of production, available markets, farmer preferences, etc. Consequently, the largest possible area is devoted to the crop which enhances the potential for greatest yields or economic returns to the producer (Tables 26, 35, 67 and 69), unless pests, limited water, or other factors limit yields. A favourable economic return increases the potential that the farmer will invest in suitable soil and water conservation practices. In one example (Table 26), continuous wheat yields on the harvested area were lower because of lower soil water contents than on the fallowed area, but yields were higher for continuous wheat on a total-area basis. Fallowing is further discussed in Section 4.2

An advantage of continuous cropping from an economical viewpoint is the relatively low capital investment for equipment, especially where production is limited to only one crop or possibly a few similar crops that can be produced with the same equipment. As more types of crops are produced, either in rotation or continuously on separate areas; the complexity of accoutrements required generally increases. While tillage for all crops can probably be accomplished with the same equipment, seeding appliances or components of the equipment will differ (for example, drills vs. row-type planters, plates for different types of seed, etc.). Likewise, different types of crops require different types of harvesting equipment (for example, root crops, grains, cotton, sugarcane, etc.), all of which result in a need for greater capital expenditures for equipment.

The influence of continuous cropping on soil and water conservation is related to the type of crop grown. As a rule, continuous production of high-residue crops aids soil and water conservation whereas continuous production of low-residue crops is detrimental to soil and water conservation.

Continuous cropping of small grains is one of the most effective soil and water conservation practices, especially when supplemented with residue-based tillage practices (Papendick and Miller 1977) and when the crop is growing during the major period of erosion. An example of the latter is winter wheat in the Great Plains and Pacific Northwest (USA). Wheat is planted in the autumn and usually provides good ground cover during winter and early spring when the potentials for erosion by wind (Great Plains) and water (Pacific Northwest) are greatest. Because tillage and natural weathering destroy residues, the potential for erosion is usually higher in a crop-fallow system than with continuous cropping. Soil losses in a fallow system may be 10 to 15 times greater than with continuous cropping whereas adequate surface residues with continuous cropping reduce runoff (Papendick and Miller 1977). Runoff is further reduced because the soil is generally drier with continuous cropping. On fallowed land, stored soil water makes further water infiltration difficult late in the fallow period (Papendick and Miller 1977; Johnson and Davis 1980).

Continuous growing of crops that produce relatively small amounts of residue or where residues are removed for other purposes or destroyed by insects (Barber et al. 1980) often results in major soil and water losses. Residue production is generally low for all dryland crops in semi-arid and arid regions, and sometimes even in subhumid regions, especially for crops such as soybeans, cotton and groundnut. Where residue amounts are inadequate for effective management to conserve water and soil resources, other supporting practices may be required (see Section 5).

An advantage of continuous cropping related to crop residues is the maintenance of soil N and C (organic matter) contents at generally higher levels than with alternate crop-fallow systems. Examples from Haas et al. (1957) are shown in Table 71. Similar results were reported by Johnson and Davis (1972) and Unger (1968). More N was lost with row crops than with small grains, and usually more with crop-fallow than with a continuous cropping system. Trends for C were similar to those for N, but the magnitude of losses was greater for C (Haas et al. 1957). Greater losses with row crops result from more plant materials being removed at harvest, severe erosion and increased aeration due to cultivation (Brengle 1982).

Table 71 PERCENTAGE CHANGE IN NITROGEN AND CARBON OF SURFACE SOILS UNDER CONTINUOUS AND ALTERNATE CROPPING WITH SMALL GRAINS AND ROW CROPS (from Haas et al. 1957)

Location	Years cropped	Small grains: Continuous cropping		Small grains: Alternate fallow		Row crops: Continuous cropping		Row crops: Alternate fallow	
		%N	%C	%N	%C	%N	%C	%N	%C
Mandan, ND	30	-18	-22	-27	-28	-36	-38	-40	-44
Archer, WY	34	-26	-35	-34	-43	-41	-52	-41	-52
Colby, KS	30	- 9	-21	-25	-28	-30	-40	-25	-44

The skills required of a farmer are related to the complexity of the cropping systems employed. Although some one-crop systems require a relatively high level of management, the level required for continuous cropping is usually less than for systems involving more than one crop, either in rotations or when grown on separate areas. The lower level required with continuous cropping results from the relatively few operations involved for tillage, planting, pest control and harvest. With rotations or more crops, the above operations may be different for each crop, thus resulting in a more complex management system.

The disadvantage of continuous cropping with respect to soil and water conservation has been discussed. Other disadvantages include the potential for greater pest problems (weeds, insects, diseases), poor use of soil water and nutrients, and a greater risk of crop failure.

Some pests cause greater problems with continuous cropping than with other systems because the pests are compatible with or favoured by the crop being grown. For example, weeds may have similar life cycles or be physiologically similar to the crop. Even though of similar life cycle, weeds that are physiologically different from the crop can sometimes be controlled with herbicides. Some examples of weed pests in this category include henbit and tansy mustard in winter wheat, pigweed in sorghum and maize, and annual grasses in cotton and soybean[1] . However, when weeds and crops are similar physiologically and with respect to life cycle, control with herbicides or by cultural techniques is difficult. Examples include barnyard grass, foxtail, fall panicum, crabgrass and sandbur in sorghum and maize; cocklebur and pigweed in soybean and cotton; and cheatgrass, hairy chess and downy brome in winter wheat and other winter small grains. Volunteer crop plants may be especially troublesome in succeeding years when crops are grown continuously (Unger and McCalla 1980).

As for annual weeds, perennial weeds also tend to increase with continuous cropping when the weeds and crops have similar growth periods and physiological characteristics. Some troublesome perennial weeds in the USA include Johnson grass, quackgrass, nutsedge, field bindweed, leafy spurge, perennial sow thistle, Bermuda grass, Canada thistle, horse nettle, silverleaf nightshade, Russian knapweed and woollyleaf bursage (Wiese and Staniforth 1973[1] .

When such weeds are present and cannot be effectively controlled by tillage or herbicides in a continuous cropping system, then a rotation involving crops of different growth cycles or physiological characteristics may be the most effective and economical control method available. Fields with summer annual weed problems can be rotated to winter grain crops. Weeds can then be controlled with tillage or herbicides during the period between crops. Conversely, fields with winter weeds can be rotated to spring or summer-planted crops. Rotations permit the selection of the most competitive crops against the most troublesome weeds (Wiese and Staniforth 1973). A crop rotation or even a crop-fallow system and use of intensive weed control measures during the period between crops may be necessary to reduce or eliminate a severe infestation of troublesome weeds (Unger and McCalla 1980).

The effect of crop arrangement in time and space (continuous cropping, rotations, etc.) on pests is illustrated in Fig. 68 (Section 3.2.4.i). In general, continuous cropping of one species is more conducive to pest problems than rotations. Pest problems (insects, diseases, etc.) can be controlled by using sequences of crops having the fewest number of pests in common. The best control is usually obtained when botanically unrelated crops follow one another (Litsinger and Moody 1976).

Depth of water use from soil profiles varies with crops grown and soil conditions. For example, sorghum for grain extracted water to a depth of only about 1.2 m in a Pullman clay loam in Texas (USA) (Musick and Sletten 1966; Unger and Wiese 1979), but to about a depth of 2.0 m in

1 See Appendix 6 for scientific names of weecds.

Richtield silty clay loam in Kansas (Musick and ,Sletten 1966). Consequently, where sorghum was grown continuously, some water and possibly nutrients remained deep in the soil profile and eventually percolated through the profile, especially in the Pullman soil. Some of the water and nutrients could be salvaged by growing deeper-rooted crops in rotation with sorghum. On Pullman clay loam, for example, sunflower grown after sorghum extracted water from depths of about 1.8-3.0 m (Jones 1978; Unger 1978c, 1982d), winter wheat extracted water to a depth of about 1.8 m (Johnson and Davis 1980), and alfalfa extracted water and N from a depth of about 4.5 m (Mathers et al. 1975b). Growing crops that have the potential to extract water and nutrients from different depths in a rotation results in more efficient water and nutrient use. It also increases the potential to store more water subsequently in the soil.

A disadvantage of continuous cropping, especially for dryland crops in arid to semi-arid regions, is the increased likelihood of crop failure due to inadequate soil water or precipitation to support a harvestable or economical crop yield. At Bushland, Texas, for example, winter wheat yielded less than 340 kg/ha of grain nine times between 1942 and 1969 with continuous cropping, but only six times with a wheat-fallow sequence (Johnson and Davis 1972). The 340 kg/ha was arbitrarily chosen as the level for crop failure. Even such yields, however, may be harvestable at some locations. The potential for crop failure may also be greater with continuous cropping due to insect, disease and other pest problems.

4,2 CROP ROTATIONS

Crop rotations are of two general types. In the first, an area is intensively cropped for one or a few years, then abandoned or fallowed for a longer period for soil fertility restoration, during which period other areas are cropped. This is the system of shifting cultivation described in Section 3.2.1, and it will not be further discussed. The crop rotations discussed in this section, the second type, involve the growing of one or more crops alternately with fallow or with each other (when more than one crop is involved). The entire area is not fallowed or abandoned, as with shifting cultivation.

Crop rotations may be simple such as the wheat-fallow system where one crop is produced in 2 years, or complex where several crops are grown in a system requiring five or more years for completion (Stewart et al. 1975). A detailed discussion of different rotations is not practical for this report. Hence, the major emphasis is on the advantages and disadvantages of crop rotations which have an influence on soil and water conservation. Crop rotations are used for a number of reasons, including soil conservation, water conservation, improved pest control, improved soil conditions, shifting of resources, and more reliable or improved crop yields.

Relatively high yields and possibly the greatest economic returns would be achieved if the most desirable crop could be grown continuously. However, because of water, pest, fertility or other- limitations, continuous cropping may not be possible. In addition, it may result in a high potential for wind or water erosion, especially for crops that produce small amounts of residue. In such cases, improved soil conservation can be achieved by growing low and high-residue producing crops in rotation. Some examples are rotations involving sorghum and wheat; peas and wheat; soybeans and wheat or maize; maize, wheat and meadow; cotton and sorghum; and maize and grasses. In each rotation, the first-mentioned crop normally produces residues that are less effective for controlling erosion, either by water or by wind, than the other crop. Consequently, a rotation involving crops that produce more residues results in at least part of the area being protected against erosion at least part of each cycle as compared with continuous cropping of only the erosion-susceptible crop.

The effect of crop rotations on potential soil losses due to water-erosion, as determined by the Universal Soil Loss Equation, is illustrated by the crop management factor, C (discussed in Section 3.2.l.iii Potential for soil erosion). In all cases where a high-residue crop is included in the rotation, the potential for soil loss is lower than where the low-residue crop is grown continuously. Crop management practices that affect the C values include tillage, rotations and residue management practices. When the potential for erosion at a given location cannot be reduced to acceptable levels by crop management, then other supporting practices must be used to control erosion. These are discussed in Section 5. Control of wind erosion is also aided by residues, as has been previously discussed. Alternate methods of controlling wind erosion where residues are not adequate or available have also been discussed.

Some advantages of crop rotations with respect to water conservation and improved water utilization were mentioned in the discussion of continuous cropping (Section 4.1). Rotations also improve water conserva-tion and utilization through reduced runoff due to (a) improved crop cover which decreases soil dispersion, (b) use of plants that impede water flow across the surface (grasses, legumes, other close-growing crops), (c) use of crops that are growing during critical runoff and erosion periods, and (d) use of crops producing large amounts of residue that can be managed for runoff and erosion control. Effects of residues on runoff and water erosion are shown in Tables 8, 10, 11, 12, 21, 31, 32, 43, 46 and 47.

Rotations further aid water conservation by allowing the use of alternate crops, tillage methods and other practices to control weeds and other pests that use water directly or result in inefficient use of water by crop plants. Rotations are especially beneficial to control troublesome weeds which directly compete with plants for water and have a major-influence on crop yields (Tables 6 and 7). While rotations help to control pests, best control can be achieved by pest management which includes the use of pesticides, resistant varieties, natural enemies and cultural practices (Litsinger and Moody 1976).

Inclusion in a rotation of crops which produce large amounts of residue is beneficial for soil and water conservation when the residues are managed on the soil surface. Crops producing much residue also improve soil and water conservation through their influence on soil conditions when the residues decompose on the surface or when they are ploughed under. Decaying residues release substances that cement or bind soil particles together into secondary units or aggregates. If water stable, the aggregates are of special value for maintaining high water infiltration, good soil structure and good plant growth. Large stable surface aggregates are also important for controlling wind and water erosion (Unger and McCalla 1980).

Soil aggregation is also enhanced by substances secreted by soil organisms such as bacteria, fungi, actinomycetes (Donahue et al. 1977), and earthworms (Hopp and Slater 1961), which use crop residues as their food source. Earthworms are especially beneficial for improving soil structure and maintaining high water infiltration rates (Hopp and Slater- 1961).

Crop rotations that include grasses or legumes have long been known to increase soil aggregation and maintain organic matter contents at higher levels than do continuous row crops (Johnston et al. 1943; Mazurak et al. 1955; van Bavel and Schaller 1951; Wilson and Browning 1946). On Marshall silt loam in Iowa (USA), aggregates were largest with continuous bluegrass and successively smaller after red clover, oats and maize in a 10-year rotation, and after continuous maize. With continuous maize, organic matter content decreased from 3.39% in 1931 to 2.86% in 1942. The rotation maintained organic matter contents at levels similar to those with continuous bluegrrass. Less runoff and erosion were associated with the larger aggregates and higher organic matter contents. Yields of rotation and continuous maize were similar when water was limited, but higher with the rotation when water was adequate (Johnston et al. 1943). Similar results were reported by van Bavel and Schaller (1951) and Wilson and Browning (1946).

Soil aggregation and water infiltration decreased and erosion generally increased when row crops replaced sod crops (Adams 1974; Jensen and Sletten 1965; Mazurak and Ramig 1963; van Bavel and Schaller 1951). The residual effect on aggregation increased with age of sod before ploughing. Aggregation and water infiltration generally increased with the age of sod when grasses replaced grain crops (Mazurak and Conard 1959; Mazurak and Ramig 1962; Mazurak et al. 1960). About 4 years in sod were needed before substantial increases in water infiltration were measured (Mazurak et al. 1960) . However, in tropical regions, the first year of grass resulted in the acquisition of 80% of the resistance to erosion and only 15% the second year. Because of the rapid development of resistance to erosion and the rapid breakdown of organic materials, short periods of grasses and crops are recommended for tropical regions (Hudson N. 1981; Juo and Lal 1977). As a group, cool-season grasses affected aggregation and water infiltration more favourably than warm-season grasses (Mazurak and Conard 1959). Consequently, it is more difficult to maintain good aggregation and high water infiltration rates in warm tropical regions than in cooler regions by managing crops and their residues (Hudson N. 1981).

In addition to the effects of residues on soil physical conditions, residues also affect soil chemical conditions because they contain nutrients that are released for subsequent plant use when they decompose. This is especially true when the residues are from legumes which have lower C:N ratios than non-legumes (Lyon et al. 1952). The legumes provide more N for subsequent crops than non-legumes, both by N released by decay of above-ground residues and by N fixed on roots by soil bacteria. Some of the N fixed by bacteria is used by the host plant; the remainder remains in root tissues or sloughed nodules from which it is released by decay for subsequent use by other plants (Lyon et al. 1952). Crop rotations involving legumes are highly important, especially in regions where fertilizer N supplies are limited and expensive, as in many developing countries or any other cropping situation where capital is limited.

Crops differ with respect to soil physical requirements for optimum growth and yield (Larson and Allmaras 1971; Taylor et al. 1966). Consequently, each crop in a rotation may require a different tillage practice. Use of a rotation which requires different depths and types of tillage for different crops may, therefore, prevent the development of soil crusts, plough pans, or other dense layers which could cause problems of seedling emergence, soil aeration, root penetration, or root proliferation.

Where tillage for one crop results in an unfavourable condition, another type of tillage for a different crop may alleviate the problem. In addition, the different crop itself may remedy the adverse conditions (Hudson N. 1981). The rotation of tillage methods and crops combined with the resultant improved soil conditions should lead to improved soil and water conservation. This would result from better plant growth, which provides more plant materials for direct protection against erosion, and more residues for possible management, improved soil conditions for greater water infiltration, and improved soil aggregation which results in a lower potential for erosion.

In contrast to continuous cropping, rotations involving two or more crops permit the shifting of input and output resources for more efficient use of available land and water resources. Shifting of resources allows operations such as tillage, planting, cultivation, irrigation and harvest of a particular crop to be performed in a more timely manner because a smaller area is devoted to any given crop. In a one-crop system, only a limited area can, for example, be planted at the optimum time with available equipment and labour, and yields generally are lower when the crop is planted at a suboptimum time (Hoeft et al. 1975). By growing crops that require operations at different times, equipment and labour resources are used more effectively throughout the year.

In addition to more effective use of equipment and labour, shifting of resources results in expenses being incurred and income being derived at different times. Income may be in the form of food gathered for direct consumption, trading of products for other goods, or sale of crop products for cash. Finally, rotations involving fallow or two or more crops minimize the chances of complete crop failure due to unexpected adverse conditions, such as inclement weather (drought, excess rainfall, frost, etc.), insects and plant diseases. Many farmers with small holdings and a few resources cannot afford to lose a crop. If the crop fails, there is no food. Consequently, a rotation that minimizes the risk of complete failure is especially important (Wright 1977). For market-oriented enterprises, crop rotations minimize the possibility of major financial losses due to complete dependence on one crop for which poor prices may prevail at market time.

Rotations have variable effects on crop yields. With adequate water-, nutrients and other input resources, combined yields for all crops grown continuously on separate areas are usually not too different and may be higher than when the same crops are grown in rotation (Constantinesco 1976; Jones 1975; Unger 1972).

However, when the rotation permits better overall utilization of water, nutrients, etc., and one crop provides improved conditions for the other crop or crops, then there are usually yield increases with the rotation system (Amemiya 1977; Constantinesco 1976; Hudson N. 1981; El Fakhry and Sultan 1980; Stallings 1957; Van Doren et al. 1977).

Use of rotations involving fallow (for example, a wheat-fallow system wherein one crop was produced in 2 years) resulted in lower crop yields than continuous cropping (Johnson 1950; Johnson and Davis 1972; Johnson et al. 1974; Jones 1975; Unger 1972) because part of the land was not cropped and, therefore, yields on a total-area basis were relatively low. Even under such conditions, a rotation involving fallow may be desirable because it minimizes the possibility of crop failure (Black et al. 1974; Johnson et al. 1974; Leggett et al. 1974). Also, yields in a fallow system (wheat-fallow in Turkey) needed to be only about 50 percent greater than with continuous cropping to result in an economic advantage for the farmer (Wright 1977) because of less frequent planting, harvesting, etc. At other locations, the economic breakeven point may be different, but rarely would a doubling of yields be required of the crop-fallow system.

At three locations in the central Great Plains (USA), long-term average winter wheat yields were 650 kg/ha in a continuous cropping system and 1 630 kg/ha in a wheat-fallow system. The more than doubling of yields was a definite economic advantage for the rotation system and wind erosion was effectively controlled by establishing and maintaining a vegetative cover on land during the fallow and cropping periods (Greb et al. 1974). Wheat yields were also more than doubled by fallowing as compared with continuous cropping at some locations in the northwest USA (Leggett et al. 1974). The same authors, however, considered fallowing to be generally non-essential because good yields were possible with annual cropping and because fallowing promoted (1) inefficient use of total precipitation, (2) erosion, (3) destruction of soil organic matter and loss of nutrients, and (4) formation of seepage and salty areas (saline seeps) in the fields. Increased formation of saline seeps in the northern USA was also attributed to fallowing (Black et al. 1974).

Some of the disadvantages of some rotations, namely, the hazard of greater erosion, lower total yields and development of saline seeps, were discussed with the advantages of rotations in the preceding paragraphs. Other potential disadvantages include the need for more equipment, for greater skill in management and the lower production of high value crops.

The increased equipment requirement with crop rotations as compared with continuous cropping is mentioned in Section 4.1. Whereas the subsistence or low capital input farmer may accomplish all production and harvesting operations with the same equipment, regardless of cropping system, a greater variety of equipment is usually required in mechanized agriculture for crop rotations than for continuous cropping, especially when rotations involving two or more crops are used. The greater variety of equipment with multiple-crop systems results from specific equipment needs for certain crops for tillage, planting, cultivating and harvesting and, therefore, adds to overall production costs. However, soil and water conservation can be enhanced when a wide array of equipment is available and used wisely. This entails using the equipment that provides the required or desired conditions for a given crop, but still conserves soil and water resources. This may be no-tillage for some crops and clean tillage for others, even at the same location. By having more types of equipment to select from, the requirements of a particular crop can be met more readily.

A shift from continuous cropping to crop rotations usually results in a shift to a more complex crop production operation and, consequently, the need for greater managerial skill by the farm operator. Greater skill is required because different crops may have different requirements for tillage, planting, pest control and harvesting. Although some one-crop systems require a relatively high level of management, an even greater level is often required when another crop is added to a system.

A relatively constant supply of a variety of foods is usually the goal of a subsistence farmer. However, in a market-oriented system, one or a few crops are considered desirable because of ease of production, good yields, established markets, and profitable prices. Consequently, the producer strives to produce more of these crops. Where rotations involving other than only the most economically desirable crops are involved, they may result in an economic disadvantage for the producer, especially on a short-term basis. However, if soil and water resources are conserved, a long-term economic benefit may be achieved by use of the rotation.

4.3 MULTIPLE CROPPING

Multiple cropping systems are similar to crop rotations involving more than one crop in that different crops may occupy the land at different times. However, whereas crop rotations involve a complete shift to another crop, both in time and space, multiple cropping involves growing two or more crops closely together in time and space. Included under multiple cropping are sequential cropping and intercropping. These terms, and those of some subsystems, are given and defined in Table 72 (Andrews and Kassam 1976).

Multiple cropping, as a rule, results in more intensive use of land than is achieved with continuous cropping and crop rotations. Whereas usually only one crop per year is obtained with continuous cropping or rotations, two or more crops per year are obtained with multiple cropping, except in arid areas where only one crop can be grown every 2 years because of water limitations (Table 72). Such systems as the latter are synonymous with a crop-fallow rotation as discussed in Section 4.2

Sequential cropping is adaptable to any type of cultivation system (shifting, labour intensive, animal and small tractor, and modern high-

Table 72 DEFINITIONS OF THE PRINCIPLE MULTIPLE CROPPING PATTERNS (from Andrews and Kassam 1976)

MULTIPLE CROPPING: The intensification of cropping in time and space dimensions. Growing two or more crops on the same field in a year.

l. SEQUENTIAL CROPPING: Growing two or more crops in sequence on the same field per year[1] . The succeeding crop is planted after the preceding crop has been harvested. Crop intensification is only in the time dimension. There is no intercrop competition. Farmers manage only one crop at a time in the same field.

1.1	Double cropping	Growing two crops a year in sequence.
1.2	Triple croppping	Growing three crops a year in sequence.
1.3	Quadruple cropping	Growing four crops a year in sequence.
1.4	Rattoon cropping	The cultivation of crop regrowth after harvest, although not necessarily for grain.

2. INTERCROPPING: Growing two or more crops simultaneouslv on the same field. Crop intensification is in both time and space dimensions. There is intercrop competition during all or part of crop growth. Farmers manage more than one crop at a time in the same field.

2.1	Mixed intercropping	Growing two or more crops simultaneously with no distinct row arrangement.
2.2	Row intercropping	Growing two or more crops simultaneously where one or more crops are planted in rows.
2.3	Strip intercropping	Growing two or more crops simultaneously in different strips wide enough to permit independent cultivation but narrow enough for the crops to interact agronomically.
2.4	Relay intercropping	Growing two or more crops simultaneously during part of the life cycle of each. A second crop is planted after the first crop has reached its reproductive stage of growth but before it is ready for harvest.

1 The farming year is 12 months except in arid areas where only one crop can be grown every 2 years due to water limitations. In these areas sequential cropping involved growing two or more crops every 2 years.

technology) (Andrews and Kassam 1976). It is merely an intensification of crop production in the time dimension where water and other resources (labour, equipment, capital, etc.) are adequate. Sequential cropping affords an opportunity to use land and water resources effectively throughout the period that is favourable to growing crops. By having a crop on the land for most or all of the year, the potential for erosion is also decreased.

In warm, humid regions, year-round crop production is possible with sequential cropping, provided adequate water is available. In temperate regions, the length of growing season may be limited by low temperature and low solar radiation in winter months. Where either water or temperature limits the growing season, a rapid change from one crop to the next is usually desirable so that each crop has adequate time to reach its potential yield under the prevailing conditions.

Strategies for intensifying sequential croppinq include using short-maturity cultivars, growing rattoon crops, harvesting crops in the immature state, transplanting slow growing crops, and using minimum or no-tillage systems (Allen et al. 1975; Bradfield 1969; Hoeft et al. 1975). No-tillage planting has been particularly beneficial for establishing the second crop in a double cropping system where the growing season fnr the second crop is limited (Allen et al. 1975; Hoeft et al. 1975; Jeffers et al.1973; McKibben and Oldham 1973; McKibben and Pendleton 1968), mainly because of more timely planting of the second crop, time saved in establishing it, and water conserved by not disturbing the soil.

In contrast to sequential cropping, which is generally adaptable to all cultivation systems, intercropping is adaptable mainly to the shifting, labour intensive, and animal and small tractor cultivation systems. Inter-cropping is seldom adaptable to modern high-technology cultivation systems because the crops are grown in close proximity to each other which results in intercrop competition during at least a part of the growth period and makes use of modern technology (large equipment, herbicides, etc.) impractical or impossible. Some intercropping, however, is practised in modern high-technology systems by seeding a second crop (e.g. soybeans) in skipped rows within a field of the primary crop (wheat). Average yields for-each crop are approximately 65-80% of the yields obtained without inter-cropping (D.M. Van Doren, Wooster, Ohio, personal communication).

Although use of mechanized equipment is possible when a row or strip intercropping system is used, intercropping is essentially a labour-intensive crop production system. Through intensive cropping, some exceptionally high yields were obtained at some tropical and subtropical locations where a year-round growing season and adequate precipitation prevailed. Examples of some intensive cropping systems are given in Section 3.2.2.ii.c. Crop production practices included intercropping, trans-planting, rattooning, etc. Use of these practices is, however, not restricted to tropical or subtropical locations, but can be used anywhere. The overall goal is to have one or more crops actively growing whenever conditions for plant growth are favourable. Such practice usually results in most efficient use of water because it is used by crops soon after it is received and, therefore, evaporation from soil is reduced. In addition, use of soil water by plants increases the potential for storage of subsequent rainfall, thus decreasing the potential for runoff and erosion. Also, the plant cover provides further protection against erosion.

In the examples given in Section 3.2.2.ii.c, water supplies and temperatures were favourable for year-round crop production. At other locations, limited water supplies or unfavourable temperatures may restrict crop production to certain periods of the year. Other factors such as light, radiation, daylength, etc. also affect crop production and must be considered in the development of intensive cropping systems for a given location. However, the following examples emphasize only the effects of seasonal water supplies and temperature on intensive production of annual crops. It is assumed that crops grown in the systems are compatible with respect to their light, space, nutrient, etc. requirements, and that soil conditions, pest control, etc. are adequate for the crops.

Case I Water supplies and temperature favourable throuqhout the year

The examples given in Section 3.2.2.ii.c pertained to crop production where water and temperature conditions were favourable throughout the year. Potential yields are highest under these conditions.

Case 2 Adequate water, seasonally cool (or hot) temperatures

In this case, year-round crop production is possible if crops are available which tolerate cool (or hot) temperatures. Crops such as cereal grains, grasses and some legumes tolerate relatively low temperatures and can be grown during the cool season. Other crops such as sorghum, millet, cotton, etc. tolerate relatively high temperatures. Therefore, these crops should be the basic crops during the cool or hot seasons, respectively. Then, as temperatures moderate, other adaptable crops can be established by any of the different subtypes of intercropping to assure continued crop growth when the basic crop reaches maturity.

To intensify crop production where winter temperatures are too low for crop survival, crops should be established as soon as temperatures moderate sufficiently. Since the soil temperature requirement for germination may be higher than that for plant survival, plants can be started in sheltered areas or indoors, then transplanted to the field when conditions become favourable. This is practial for limited areas and extends the growing season. Other adaptable crops can then be planted throughout the period when conditions are propitious. Toward the end of the warm season, crops can be grown which tolerate relatively cool temperatures and for which the edible part is produced in the soil where it is protected against low temperatures. Crops in the latter group include carrots and some radishes.

Case 3 Seasonal water supply, favourable temperatures

Several opportunities are available to intensify crop production through intercropping at locations where distinct wet and dry seasons prevail. One method is to dry-plant seeds before the onset of the rainy season, thus permitting germination as soon as rainfall is adequate to wet the soil. Such practice, however, may be risky, especially if initial rainfall is limited and not reliable. The seed may germinate, but the seedlings fail to survive if additional rainfall is delayed. In other cases, germination and emergence may be erratic. These problems can sometimes be overcome by conserving water from the last rainy season or occasional rainfall during the dry season by appropriate conservation measures. Mulches of crop residues or other materials, or even of dry soil, may conserve adequate water for early crop establishment (see Sections 3.2.4.iii and 3.2.5).

Crop establishment early in the rainy season is possible by transplanting in a field plants started elsewhere. This may be practical for limited areas. Then other crops can be established as appropriate throughout the rainy season, provided soil conditions permit such activity. Toward the end of the rainy season, crops can be grown which are capable of extracting adequate soil water for completing their life cycle. Forage crops may be especially appropriate for late in the rainy season because they can be harvested at any growth stage or the residues could be managed during the dry season to aid erosion control and to conserve water from scattered rains that may occur during the dry season.

Case 4 Seasonal water supply, seasonal temperatures

Crop production where water supplies and temperatures are favourable during the same season is essentially the same as when one or the other limits production during a given season. In such situations, early establishment of adapted crops followed by intercropping of other crops at appropriate times leads to potentially high production. When water supplies and favourable temperatures do not occur in the same season, then water conservation is extremely important and the crops should be established as soon as practical when temperatures become low enough to reduce losses of water due to evaporation. Intercropping may have limited potential in this situation because the soil may contain only enough water for one or- possible two crops.

Most regions of the world have periods of low and high rainfall at different times of the year, as covered by Cases 3 and 4. Of these, the situation covered by Case 3 is probably most common with respect to intensive multiple cropping. Therefore, some representative cropping sequences are given to illustrate the variety of crops and complexity of systems used in certain countries.

In Cameroon, intercropping of perennial and annual crops involves coffee, plantains or bananas, maize, cocoyams, drawf bears and local vegetables. Where the cropping period is followed by a fallow period, root crops (yams or cocoyams) start the sequence and are intercropped with cereals such as maize. Legumes are used toward the end of the rainy seasor, and cassava is planted at the end of the dry season and continues during the second year, after which the land is followed. In other parts of Cameroon, typical intercropped species are: (1) maize, cocoyam, Colocasia, yam and vegetables, and (2) potato, maize and local vegetables. Sorghum and cotton or sorghum and groundnuts may be sequentially cropped (Lyonga 1980).

Farmers in southern Nigeria intercrop maize, cassava, vegetables and cocoyam where little or no tillage is performed (Agboola 1980). Where ridges or mounds are constructed, yams may be planted on the mound; maize, okra, melon and cassava at lower parts of the mound; and rice between the mounds (Figs. 57, 58). The vast diversity of crop combinations used at different locations in Africa is given in Table 73. Other typical icter-cropping examples are maize and beans in Central America and tropical South America, and rice and melons followed by rice, cabbage and maize in Taiwan (Agboola 1980).

The foregoing examples illustrate the advantage of multiple croppirg (sequential cropping or intercropping) systems with respect to their- potential for growing a large variety of foods. This potential plus that for obtaining high total yields were also demonstrated and discussed ic Section 3.2.2.ii.c. Multiple cropping systems have another potential: minimizing soil erosion as compared with conventional cropping systems (Siddoway and Barnett (1976). Grasses and other close-growing crops, when included in the intercropping system, are especially effective for minimizing soil erosion, but other crops do the same through ircreased vegetative cover during critical erosion periods. Multiple cropping, especially intercropping, is most efficacious for controlling erosion at locations where year-round crop production is possible, provided an adequate vegetative cover is maintained. Where crop productior is limited to various seasons because of water-, temperature or other limitations, multiple cropping may enhance erosion control during the growirg perriod, but may have no particular value for other seasocs unless more residue is produced and then managed for erosioc coctrol. The same prirciples of erosion control that have been discussed ir other sections for convertioral systems are applicable for multiple cropping systems where residue supplies are limited.

As a rule, multiple cropping in space and time is more conducive to controlling weed, insect, disease and other- pests thac continuous cropping (Fig. 68) (Constarticesco 1976; Litsiccger ard Moodv 1976· nrn·-i

Table 73 CROP COMBINATIONS IN DIFFERENT LOCATIONS IN AFRICA IN 100 m^2 SAMPLE PLOTS IN RELATION TO SEEDBED PREPARATION (from Agboola 1980)

Crop	Location and seedbed preparation[1]											
	1	2	3	4	5	6	7	8	9	10	11	Percentage frequency
Dioscorea rotundata	X	X	X		X	X	X	X	X	X		82
D. rotundata (Abi)		X		X								18
D. dumetorum						X		X	X	X		36
D. bulbifera					X	X						18
D. alata			X		X	X		X				36
D. cayenensis sp.								X				9
Cassava (*Manihot* sp.)		X		X	X	X		X	X	X	X	64
Cocoyam (*Xanthosoma*)			X	X			X	X	X			45
Cocoyam (*Colocasia*)			X		X			X	X			36
Sweet potato			X									9
Musa sp.				X			X		X			27
Maize (*Zea* sp.)	X	X	X	X	X	X	X	X	X	X	X	100
Cowpea (*Vigna* sp.)			X		X							18
Groundnuts (*Arachis* sp.)					X	X	X					27
Voandzeia sp.					X							9
Sphenostylis sp.								X				9
Solanum sp.	X		X									9
Capsicum sp.									X			18
Okra (*Hibiscus* sp.)	X	X	X		X	X	X	X	X			73
Pumpkin (*Cucurbita* sp.)	X	X						X				27
Melon (*Colocynthis* sp.)	X	X	X	X		X	X					55
Telfairia sp.					X				X			18
Lagenaria sp.					X	X						18
Amaranthus sp.	X		X	X								27
Corchorus sp.	X		X	X			X		X			45
Bitter leaf (*Veroonia* sp.)									X			9
Talinum triangulare							X	X				18
Castor bean (*Ricinus* sp.)	X		X	X	X							36
Sugarcane (*Saccharum* sp.)								X				9
No. of species per sample	9	7	13	9	13	10	9	13	12	4	2	

[1] Locations and types of seedbeds were: 1 - Ogidi (mound), 2 - Abagana (mound), 3 - Umuleri (mound), 4 - Awka (mound), 5 - Ezillo (mound), 6 - Abakaliki (mound), 7 - Ikom (mound), 8 - Oron (flat), 9 - Ibam Ekpe (flat), 10 - Onne 1 (flat), and 11 - Onne 2 (flat).

1974) . While weeds are major problems in multiple cropping systems, especially in warm, humid regions, and are a major reason for using shifting cultivation (Moody 1974; Ofori 1974), weed control in these regions is usually better with multiple cropping than with continuos cropping. The improved control with multiple cropping results from the various crop and weed species having different growth habits, light requirements and abilities to compete for space, water and nutrients (Litsinger and Moody 1976; Moody 1974; Ofori 1974). Undoubtedly, closer management by the farmer, especially on small farms, results in weeds being controlled on a more timely basis in a multiple cropping than in a continuous cropping system, thus reducing the overall weed problems.

As for weeds, multiple cropping may result in fewer and less severe insect, disease and other pest problems than continuous cropping. Factors responsible include use of shorter maturing varieties, greater crop diversity (plant types, heights, leaf density, cover, etc.), use of resistant cultivars, growing of crops at a time nut of phase with the time of greatest potential for the pest, presence of effective parasites or predators, chemicals (odours, exudates, etc.) produced by certain plants, and greater distances between susceptible cultivars (Litsinqer and Moody 1976; Ofori 1974).

Although weed problems tend to he less in multiple than in continuous cropping systems, as previously discussed, weed control may be more difficult in multiple cropping (especially intercropping) systems because major tillage or herbicides often cannot be used. Major tillage, such as that with animals or tractors, may not be possible because the crops are interplanted, have overlapping growing seasons, and may be broadcast planted (not in a pattern suitable for weed control with tillage) (Litsinger and Moody 1976; Moody 1974). Even where the crops are planted in rows, inter-row cultivation does not control weeds in the row and, therefore, may require weeding by hand. Sequential cropping should not interfere with major tillage per se for weed control and other purposes such as seedbed preparation, water conservation, erosion control, etc. However, time may be limited for tillage when a rapid shift to another crop is desired. Where tillage is performed by hand, intercropping could restrict tillage, but not necessarily weed control with a hoe or cutlass, or by pulling.

Use of multiple copping systems definitely limits the control of weeds with herbicides. Because of the variety of crops grown, most herbicides cannot be used without harming some crop in the system. This is especially a problem with intercropping, and may be a problem with sequential cropping because of the residual effects of herbicides on subsequent crops (Moody 1974). As for herbicides, residues from insecticide applications to a preceding crop may also linger in the soil and adversely affect the next crop by contaminating the edible plant parts or by phytotoxic action. The residual action may, however, control other insect pests (Litsinger and Moody 1976).

The limited opportunities for tillage and for applying herbicides to control weeds are the primary reasons why multiple cropping systems, especially intercropping systems, are labour-intensive systems. Being labour-intensive may or may not be a disadvantage. It is a disadvantage where the labour supply is limited. It is usually an advantage where labour is plentiful. Farm work may be difficult and unappealing to many people. However, it provides an opportunity for employment where the labour supply is plentiful and where there are limited opportunities for employment in industry and other occupations.

5. SUPPORTING PRACTICES

Soil and water conservation is most easily and economically achieved on Class I lands (Table 2), which have few limitations that restrict their use for crop production. On such lands, wise selection and use of tillage, crops, cropping systems and other management practices usually effectively control soil and water losses.

Such management practices are also appropriate for other classes of land, but control of soil and water losses becomes increasingly more difficult and correspondingly more important for resource conservatinn on those classes of land that have severe limitations for crop production (Table 2). Ideally, land with severe limitations would not he cropped. However, because of limited areas of land with few limitations for crop production and the ever-increasing need for more food, such lands are frequently used for crop production. On them, supporting practices in addition to tillage methods, crop selection, cropping systems and related management practices may be needed to conserve soil and water resources effectively for sustained food production.

Some supporting practices can be adopted and used by incurring no or only slight additional expenses in crop production. Others entail major alterations of the land surface. Most practices are advantageous for conserving water and for controlling water erosion, and will be jointly discussed for both purposes. Practices that have particular application for one or the other will be identified as will those that have special application for controlling wind erosion.

5.1 LAND SMOOTHING

Land smoothing is the practice of moving soil from high to low points in a field (Fig. 66). By eliminating the low points, water is kept from flowing to them where its concentration could accelerate erosion or result in uneven storage in the field. In general, land smoothing aids modern mechanized farming with respect to speed of operation, precision planting, cultivation, weed control, fertilization and harvesting. It is also conducive to uniform and maximum storage of water for subsequent crop use (Gamble 1968; Singh 1974). Land smoothing is on a relatively large scale and should not eliminate micro-depressions and surface roughness (clods and ridges) which are important for controlling water and wind erosion, respectively.

5.2 CONTOUR TILLAGE

Contouring involves ploughing, planting, cultivating, etc. across the slope of the land so that elevations along rows are as near to level as practical (Figs. 35, 38, 59) (Gamble 1968). When lister tillage or ridge planting is used on the contour, the likelihood of erosion is greatly decreased (Table 74) (Stewart et al. 1975).

The practice of tilling and planting on the contour provides almost complete protection against erosion from storms of low to moderate intensity, but little or no protection against occasional severe storms that cause extensive overtopping and breaking of the contoured rows. The potential for erosion on contoured land generally increases with increases in land slope. However, lowest P values (Universal Soil Loss Equation) are for slopes from 2 to 7 percent (Table 74). As land slope decreases to values below this range, the slope approaches equality with the contour row slope and the soil loss ratio (P value) approaches l.0. At greater slopes, contour row capacity decreases and the soil loss ratio again approaches 1.0 (Wischmeier and Smith 1978).

Table 74 VALUES OF SUPPORT-PRACTICE FACTOR, P
(from Stewart 1975)

Practice	Land slope (percent)				
	1.1-2	2.1-7	7.1-12	12.1-18	18.1-24
	Factor P				
Contouring	0.60	0.50	0.60	0.80	0.90
Contour strip cropping					
R-R-M-M[1]	0.30	0.25	0.30	0.40	0.45
R-W-M-M	0.30	0.25	0.30	0.40	0.45
R-R-W-M	0.45	0.38	0.45	0.60	0.68
R-W	0.52	0.44	0.52	0.70	0.90
R-O	0.60	0.50	0.60	0.80	0.90
Contour listing or ridge planting	0.30	0.25	0.30	0.40	0.45
Contour terracing[2]	$0.6/\sqrt{n}$[3]	$0.5/\sqrt{n}$	$0.6/\sqrt{n}$	$0.8/\sqrt{n}$	$0.9/\sqrt{n}$
No support practice	1.0	1.0	1.0	1.0	1.0

1 R = row crop, W = autumn-seeded grain, O = spring-seeded grain, M = meadow. The crops are grown in rotation and so arranged on the field that row crop strips are always separated by a meadow or winter-grain strip.

2 These values estimate the amount of soil eroded to the terrace channels and are used for conservation planning. For prediction of off-field sediment, these values are multiplied by 0.2.

3 n = number of approximately equal-length intervals into which the field slope is divided by the terraces. Tillage operations must be parallel to the terraces.

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Table 75 P VALUES, MAXIMUM STRIP WIDTHS AND SLOPE LENGTH LIMITS EOR CONTOUR STRIP CROPPING
(from Wischmeier and Smith 1978)

Land slope	P values 1			Strip width 2		Maximum length	
percent	A	B	C	metres	feet	metres	feet
1 to 2	0.30	0.45	0.60	40	130	240	800
3 to 5	.25	.38	.50	30	100	180	600
6 to 8	.25	.38	.50	30	l00	120	400
9 to 12	.30	.45	.60	24	80	73	240
13 to 16	.35	.52	.70	24	80	49	160
17 to 20	.40	.60	.80	18	60	37	120
21 to 25	.45	.68	.90	15	50	30	l00

1 P values:
A - For a 4-year rotation of row crop, small grain with meadow seeding and 2 years of meadow. A second row crop can replace the. small ;rain if meadow is established in it.
B - For 4-year rotation of 2 years row crop, winter grain: with meadow seeding, and 1-year meadow.
C - For alternate strips of row crop and small grain.

2 Adjust strip-width limit, generally downward, to accommodate widths of farm equipment.

When properly used, contouring promotes uniform water storage on the entire field. When lister tillage is used, each ridge serves as a miniature level terrace and, thus, holds water on the land. Runoff at Spur, Texas (USA), from 1927 to 1952 averaged 7.0 and 5.0 cm per year from areas with sloping and contoured rows, respectively. Cotton on the respective areas yielded an average of 131 and 211 kg/ha annually (Fisher and Burnett 1953). Flat tillage methods(sweep or one-way disk ploughing) on the contour as compared with tillage without regard to contour increased wheat yields only about 10 percent, a much smaller response than for ridge planted row crops on the contour (Finnell 1944).

In India, with 129.5 cm of annual rainfall, runoff averaged 5.2 and 2.9 cm from sloping row and contoured fields, respectively. Soil losses averaged 88 and 33 t/ha and potato yields averaged 12.6 and 13.4 t/ha. The land slope was 25%. On land with 2% slope, soil loss was 14.4 and 4.4 t/ha, runoff was 38 and 13%, and maize yields were 1..3 to 1.9 t/ha on sloping row and contoured fields, respectively (Singh 1974).

Contouring has no direct value for control of wind erosion unless ridges formed by tillage increase surface roughness. Where the potential for wind erosion is much greater than that for water erosion, ridges formed by tillage sould be at right angles to the prevailing wind direction and without regard to the land slope.

5.3 STRIP CROPPING

Strip cropping is beneficial for controlling water and wind erosion. When used to control water erosion, strips of protective crops are alternated with row crops on the contour. Such strip cropping is more effective than contouring alone for controlling erosion (Table 74). The protective and cropped strips are usually of equal width (Wischmeier and Smith 1978). Recommended maximum strip widths and slope lengths are given in Table 75. Sod and winter small grain crops tend to be more effective for controlling erosion than spring grain crops. Soil eroded from the cultivated area is filtered out of the runoff water as it slows in the protective strip. Therefore, strip cropping reduces soil losses from the field, but does not necessarily prevent movement between the strips (Wischmeier and Smith 1978).

Buffer strip cropping is another type used to control erosion. This practice consists of narrow protective strips alternated with wider cropped ones. The location of strips is determined by the width and arrangement of adjoining strips in a rotation and by the location of steep, severely eroded areas on slopes. Buffer strips usually occupy correction areas on sloping land and are seeded to perennial grasses and legumes (Charreau 1977; Wischmeier and Smith 1978). Forage from grass or legume areas can provide feed for livestock.

Strip cropping is widely used to control erosion by wind (Brown 1970; Fosse 1970; Fryrear 1969; Hagan et al. 1972; Siddoway lH7U). In the Great Plains (USA), fallow and cropped areas are alternated for the production of such crops as wheat, barley and oats. Residues retained con the surface by stubble mulch tillage in a strip cropping system provide reasonable protection against wind erosion (Brown 1970) by reducing field length in the direction of prevailing winds.

In other cases, narrow strips of tall plants have served as a barrier to reduce wind erosion (Fryrear 1969; Hagen et al. 1972; Siddoway 1970), improve water conservation (Black and 5iddoway 1971), and alter plant responses (Radke and Hagstrom l976). For erosion control, the interval betwen successive barriers should be about to times the height of the barrier. Water conservation with barriers results mainly from snow trapping. A well-designed barrier with appropriate porosity traps snow uniformly on land between barriers (Black and Siddoway 1971; Lehane and Nielson 1961), thus conserving water for subsequent crop use.

Crops sheltered by strips of taller plants tended to grow taller, produce more dry matter, have a larger leaf area index, and yield more than when grown without barriers. Barriers spaced at 10 to 15 times the height of the barrier were most effective. Also, porous barriers that permitted filtering of air through the barriers were more effective than solid or dense barriers (Radke and Hagstrom 1976).

5.4 GRADED FURROWS

In contrast to furrows on the contour, which are intended to minimize runoff and hence erosion, graded furrows are designed primarily to convey excess water safely from fields with minimum erosion and little storage of water in the soil profile (Bertrand 1966). When row gradients varied from nearly zero at the upper end to about 1 percent at the lower end of a field 300 m long, soil loss was comparable to that from a terraced field in Texas (Richardson 1973). Although designed to remove excess water, graded furrows also conserve water. At Temple in Texas, runoff during a 32-month period totalled 18.7 cm from a graded-furrow watershed and 23.6 cm from a terraced watershed (Richardson 1973). Less runoff from the graded-furrow watershed resulted from the potential runoff water being more uniformly distributed over the entire field. The excess water concentrated in the terrace channels and ran off more rapidly on the terraced watershed.

5.5 BASIN LISTING

The objective of basin listing (also called tied ridging, furrow blocking, furrow damming, furrow diking) (Figs. 37, 93) is to hold rainfall in place where it falls until it infiltrates into the soil (Fig. 38). If the water is held in place, there is no runoff and, therefore, no erosion due to running water. However, some of the water is lost by evaporation.

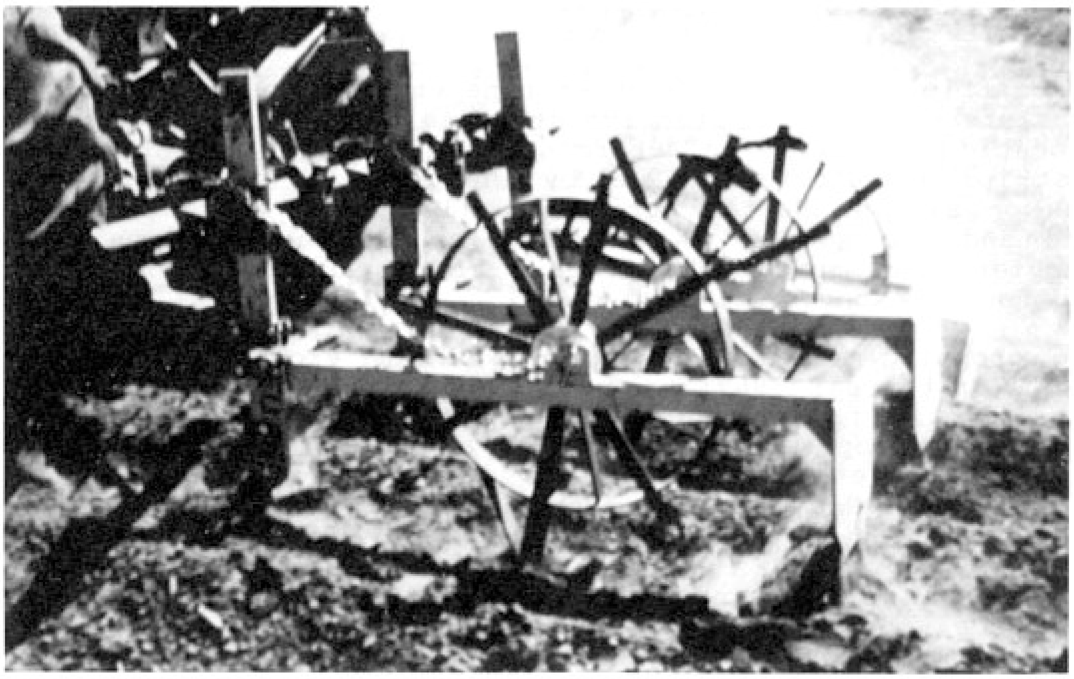


Fig. 93 Installing check dams in furrowed land (similar to basin listing) (photo provided by O.R. Jones, USDA-ARS)

Basin listing has been used at numerous locations (Ahn 1977; Hudson N. 1981) and was introduced into the southern Great Plains (USA) in the 1930s to hold, distribute and conserve potential runoff water more uniformly over the entire field. The practice was little used by 1950 because of slowness of operation, difficulties in weed control. and seedbed preparation, planting in furrows, subsequent tillage, and greater erosion during periods of high rainfall (Clark and Hudspeth 1976). Greater erosion and waterlogging during periods of above average rainfall were also problems in Africa (Ahn 1977). In addition, yield increases with basin listing were small (Daniel 1951; Locke and Mathews 1953) and stubble mulch tillage, terracing and other conservation practices were easier to manage and more popular (Clark and Hudspeth 1976).

Interest in basin listing redeveloped in the southern Great Plains in the mid 1970s because better background information and modern technology permitted using the practice without encountering the problems experienced earlier (Clark and Hudspeth 1976). Long-term data for Bushland showed that runoff was greatest during May and June when summer row crops were being established. If basins were in place during the growing season of a summer crop when rainfall is highest rather than during fallow after wheat when the potential for runoff is low, as was the case in the early studies, the water conserved could be used almost immediately and evaporation would be minimized.

A further advance favouring basin listing is the availability of effective herbicides which greatly reduce the need for cultivation to control weeds after crop establishment. However, if cultivation is necessary, equipment is now available to remove the dams, cultivate the land and replace the dams, all in one operation (Lyle and Dixon 1977).

Water conserved by basin listing increased sorghum grain yields an average of 230 kg/ha (1 650 vs. 1 420 kg/ha) at Bushland for 1975 to 1979 (Clark and Jones 1981). At Lubbock in Texas, cotton lint yields were 220 and 280 kg/ha with open furrows and basin listing, respectively (Clark and Hudspeth 1976). Increased soil water contents and crop yields were also reported from Botswana (ODA 1980). Tied ridges resulted in more water in the soil throughout the growing season than open furrows, and increased sorghum yields by 800 kg/ha. Cowpea yields were significantly increased (400 kg/ha) only for the 1973-74 crop.

An extension of basin listing is to use the practice in conjunction with sprinkler irrigation to prevent runoff. In Washington (USA), Aarstad and Miller (1973) minimized runoff and generally increased hay, potato and sugarbeet yields when basin listing was used on sprinkler-irrigated land. Runoff was also prevented by basin listing on land that was sprinkler irrigated with a low-pressure system which applied water to a smaller area than high-pressure systems (Fig. 94). Low-pressure systems reduce the energy used for crop production; thus it is a desirable practice (Lyle 1979).

To improve on the conservation and use of rainfall and irrigation water in crop production, Stewart et al. (1981) used basin listing on land planted to sorghum. Irrigation water was then applied to alternate furrows, which washed out the dams as the water advanced down slope. By using a limited irrigation approach, water advanced only partly through the field which resulted in the dams remaining in place at the lower end of the field unless major rain fell soon after irrigation. Basins at the lower end as well as those in non-irrigated furrows trapped rainfall water and prevented runoff, which increased water use efficiency for grain production.

Excess water was not a problem in the foregoing examples. Even when 11.5 cm of rain fell in a 24-hour period, no runoff occurred from a slowly permeable soil in Texas (USA) that was basin listed. Runoff totalled 3.83 cm

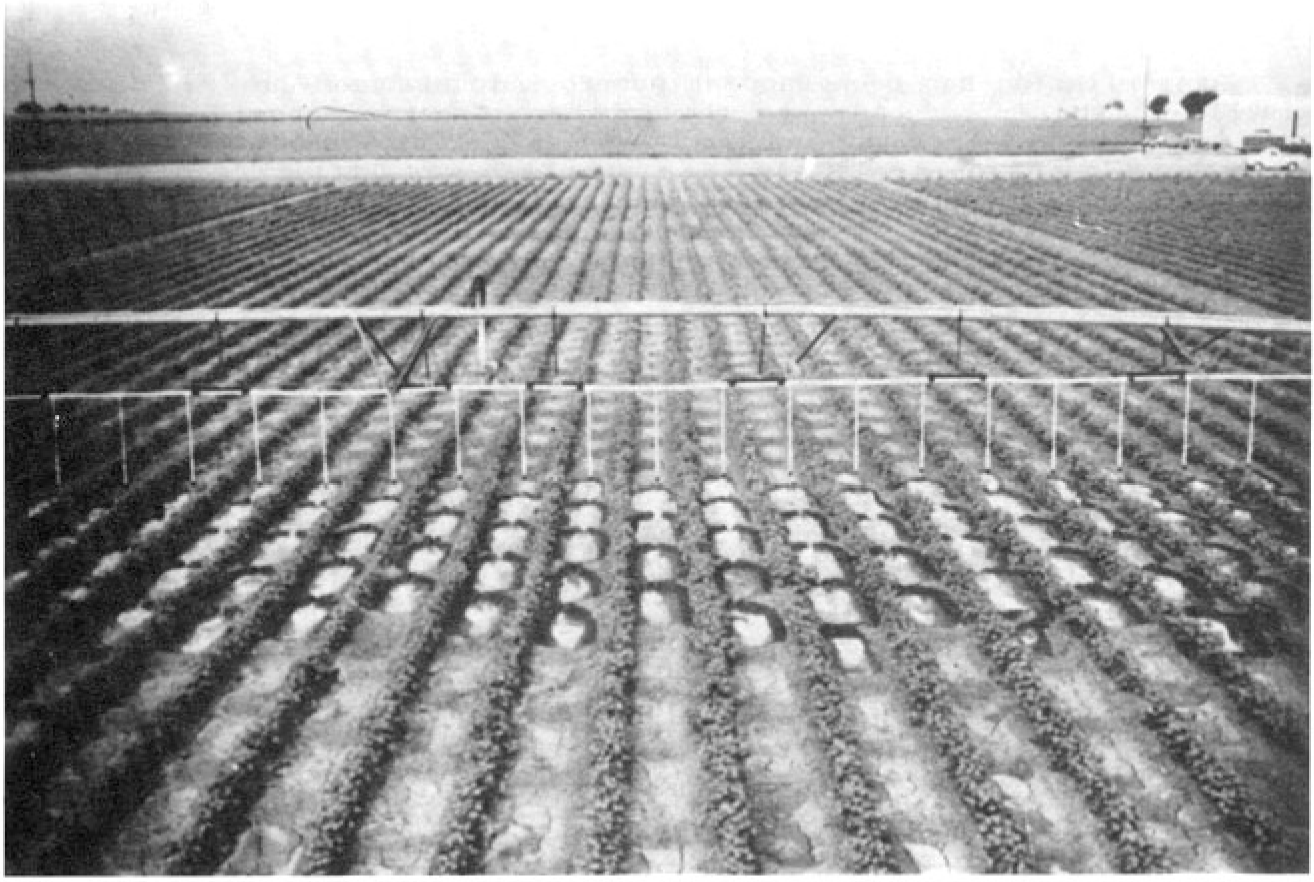


Fig. 94 Experimental low-pressure sprinkler irrigation system being used on basin-listed land (photo provided by W.M. Lyle, Texas Agric. Exp. Stn.)

from adjoining plots with open furrows (Clark and Jones 1981). Where excess water is a problem at times and water conservation is otherwise desirable, a system in which basin listing is used in alternate furrows may be a satisfactory compromise. Such system allows adequate water infiltration, but also allows excess water to escape along open furrows. Furrow gradients should be gentle to reduce the risk of erosion (Ahn 1977).

5.6 TERRACING

The foregoing soil and water conservation practices (land smoothing, contouring, strip-cropping, graded furrows and basin listing) usually involve only a small amount of surface soil manipulation and are applicable mainly to land with relatively slight slopes. As slopes increase; the potential for runoff and erosion normally increases and more intense practices are required to conserve soil and water resources. On cropland, some type of terrace is frequently used to minimize soil and water losses. Depending on prevailing conditions, terraces may be used primarily to control erosion by conveying excess water off the land at a non-erosive velocity or to retain potential runoff water on the land and, thereby, minimizing the potential for erosion.

Terraces may differ in design with respect to base width, slope along the channel, and positioning with respect to contour of the land. The broad-base terrace (Fig. 95) is the most common type on gently sloping land. For this type, the channel and ridge are cropped, usually the same as for the area between terraces. The steep backslope terrace is most commonly used on steeper land (Wischmeier and Smith 1978). However, narrow-base terraces with non-farmable steep side slopes are also used on qentlv

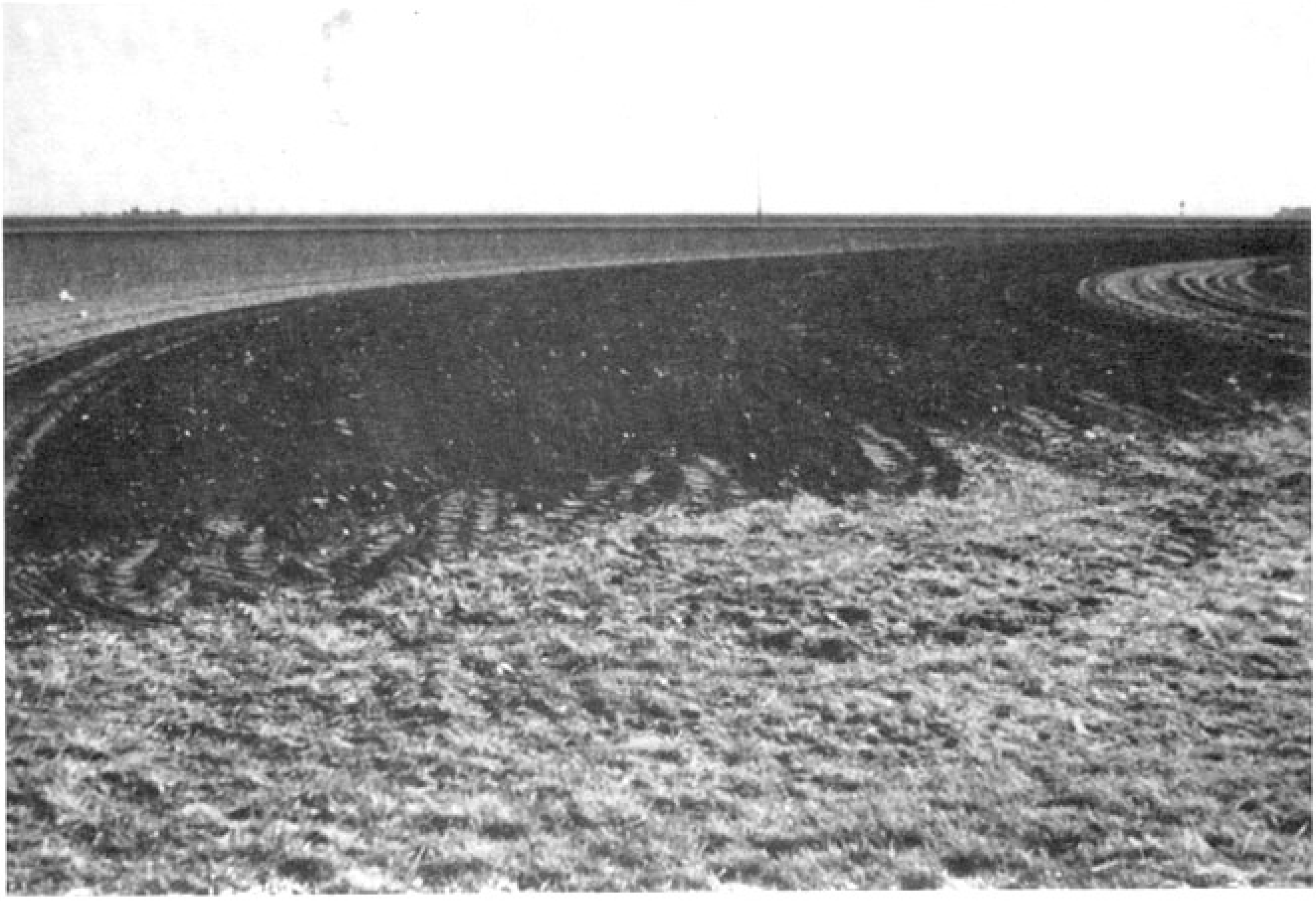


Fig. 95   Broad-base terrace on gently sloping land. The terrace is wide enough to permit use of normal cultural operations on the terrace

Fig. 96   Narrow-base, steep side slope terrace on gently sloping land

sloping land to minimize soil movement required for terrace construction (Fig. 96). The steep backslopes of narrow terraces are often sodded on steeply sloping land (Wischmeier and Smith 1978), but not on gentle slopes, especially where the terraces are used for water conservation (personal observation). In this case, sod would use water that could potentially be used for crop production.

When intended for conveying excess water from a field, terraces are constructed with a slight gradient along the channel. The gradient should be such that the water flows at a non-erosive velocity for the given soil. In addition, the gradient can be variable within a channel to improve terrace alignment, especially if underground drains are available to remove some of the water from the field (Soil Conservation Service 1977).

Broad and narrow-base terraces with level channels are sometimes used to conserve water in dryland farming areas. These terraces may have either open or closed ends (Wischmeier and Smith 1978). When ends are closed (blocked), they are usually only partially blocked so that water from above-normal rainstorms can drain from the field. When completely blocked, such rainstorms could cause sufficient waterlogging on some soils to damage crops unless the blocks were breached to drain the water.

Graded and level terraces have been evaluated at several southern Great Plains (USA) locations. In Texas, soil water contents and yields were generally higher with level terraces than with graded-channel terraces, especially when level terraces had blocked ends and contour tillage was used between the terraces (Burnett and Fisher 1956; Dickson et al. 1940; Fisher and Burnett 1953). When Foard silt loam in Oklahoma was kept relatively smooth for wheat, water stored behind closed-end level terraces increased wheat yields in dry seasons, but often decreased yields during wet seasons. During wet seasons, water had to be drained from terrace channels to prevent damage to wheat (Harper 1941).

On Pullman clay loam in Texas, grain yields of wheat and sorghum from 1949 to 1960 were similar with graded and closed-end level terraces in a wheat-fallow-sorghum cropping system. This finding led Hauser et al. (1962) to suggest using open-end level terraces which avoid the need for high terrace ridges to store large amounts of water and the need to drain water from the channels when large amounts of rainfall occur.

A variation of the level terrace is the conservation bench terrace (CBT) which is basically a level terrace with a part of the area adjacent to and upslope from the terrace levelled. The unlevelled area contributes runoff water to the levelled area (Fig. 97). This results in runoff water being spread over a larger area than possible without the levelled area. These terraces also need to be drained less frequently and conserve more water than closed-end level terraces, and minimize soil losses from the field (Zingg and Hauser 1959). However, erosion may still occur on the watershed area of the field.

A CBT system was constructed at Bushland on the slowly permeable Pullman clay loam soil with 1.0-1.8 percent slope in 1955. The unlevelled (watershed) to levelled (bench) area ratio was 2:1. Bench areas were continuously cropped to sorghum for grain and watersheds were cropped in a wheat-fallow-sorghum sequence. Results from this system were compared to those from level terrace areas and from bench-levelled (no watershed) areas. Soil water content at planting was greater on level benches of the CBT system than bench-levelled areas without a watershed (also under annual cropping) and similar to that on level-terraced fields that were fallowed about 11 months between crops (two crops in 3 years). Yields were about 50 percent higher with the CBT system than with level terraces because the level-terraced area was cropped in a wheat-fallow-sorghum system and the levelled areas of the CBT system were annually cropped to sorghum. Total

Fig. 97 Uniform distribution of runoff water on the levelled area of conservation bench terraces, Bushland, Texas, USA (photo provided by O.R. Jones, USDA-ARS)

grain production was highest with the bench-levelled system (no watershed) because the entire area was annually cropped to sorghum. However, this system increased the probability of poor yields due to low water storage in dry areas (Hauser 1968; Jones and Hauser 1975; Zingg and Hauser 1959). The major advantage of the CBT system over the bench-levelled system (no watershed) was that the CBT system required levelling of only one-third of the land. The higher yields with the bench-levelled system were not adequate to offset the additional construction costs as compared with the CBT system (Jones and Shipley 1975). To further decrease construction costs, Jones (1981) developed a CBT system with narrow benches which required that only a small amount of soil be moved for land levelling. Crop yields were similar to those obtained with the wider levelled areas.

The CBT systems at Big Spring, Texas (USA), were on a permeable Amarillo fine sandy loam soil with slopes of 1.3-1.9 percent. Watershed to bench ratios were 0:1, 2:1, 4:1 or 6:1. Cotton or sorghum yields were not increased by the CBT systems as compared to yields on control areas because the soil had a high infiltration rate and relatively low plant available water storage capacity (10.2 cm to a 1.2 m depth). Runoff was limited to high-intensity or frequent rains and the impounded runoff was mostly lost through deep percolation because of the limited storage capacity of the soil (Armbrust and Welch 1966).

The CBT systems with watershed to bench ratios of 0:1, 1:1, 2:1 or 3:1 at Akron, Colorado (USA), were on Rago silt loam with 1 percent slope. Soil water contents on the levelled areas were increased by 1.8 to 4.3 cm over those resulting from fallow during a period of below normal precipitation. Water storage in benches durinq the 7 months between crops with annual cropping was similar to that which occurred during 19 months of fallow on the watershed where a sorghum-fallow system was used. Sorghum grain yields averaged 450 kg/ha more on benches with annual cropping than on watersheds after fallow. The 2:1 watershed to bench ratio resulted in the highest yield (Mickelson 1968).

At Hays, Kansas (USA), the CBT systems, which had 0:1, 1:1 or 2:1 watershed to bench ratios, were on a slowly permeable Crete soil. Sorghum grain yields were higher on annually-cropped benches than on watersheds which were fallowed 12 months before planting sorghum (Hauser and Cox 1962).

Singh (1974) reported the results of CBT research in India where watershed to bench ratios were l:l, 2:1 and 3:1. Total grain production increased as the watershed to bench ratio increased. Total yields were 2060, 2180 and 3950 kg/ha when the ratios were l:l, 2:1 and 3:1, respectively.

In contrast to other locations, water storage in soil and alfalfa yields were more influenced by bench location for snow collection than by the watershed-to-bench ratio in a CBT system at Mandan, North Dakota, a northern USA Location. Overwinter water storage for five seasons averaged 3.6 cm on watersheds and from 12.2 to 23.1 cm on level benches. As a result, alfalfa dry matter yields averaged 3.4 tons/ha on watersheds and from 7.2 to 9.6 tons/ha on benches (Haas and Willis 1968).

The bench-levelled system (no watershed) and the CBT system with 0:1 watershed-to-bench ratio referred to in preceding paragraphs are identical. Except for being on gentle slopes (less than about 2 percent), they are also very similar to bench terraces widely used on steep slopes where other land for crop production is limited (Figs. 32, 33, 55). Extensive areas of bench terraces are in Peru, Nepal, Indonesia, Malaya, China, Japan, the Philippines, and other countries (Hudson N. 1981).

Bench terracing involves the construction of horizontal or nearly horizontal ledges with vertical or nearly vertical walls between the ledges. The vertical wall is usually supported with stone, brick or wood, except on very stable soils where it can be supported by vegetation. The terraces may be of several types including level bench, outward sloping bench, inward sloping (reverse slope) bench, step terraces and irrigation terraces. Each is usually adaptable to a particular type of crop or condition (Hudson N. 1981).

Because of the large amount of labour required to construct bench terraces, they are seldom part of modern development programmes. However, some remain from other eras and are highly important for crop production in certain countries. Besides the labour requirement, removal of excess water is also a major problem on steeply sloping land (Hudson N. 1981). Therefore, proper design, construction and maintenance of bench terraces and accompanying runoff disposal structures are highly important to minimize the potential for system failure. Some design criteria were given by Gil (1970) and Hudson N. (1981). Major factors influencing system design include land slope, soil depth, soil texture, infiltration rate and maximum expected rainfall intensity (Barber et al. 1980; Gil 1979; Hudson N. 1981). When properly designed, constructed and maintained, bench terraces have effectively conserved soil and water resources for intensive crop production on steeply sloping land for many years without failure (Hudson N. 1981). Poor design, construction and maintenance eventually lead to system failure (Fig. 69).

To minimize the labour requirement and cost of constructing bench terraces, Barber et al. (1980) and Jacobsen (1966, 1968) advocated placing soil uphill from a trench on the contour or at a slight qradient to form a ridge or bank, which is stabilized with grass. A retaining wall of stone or other materials serves the same purpose (Gil 1979). The natural processes of erosion and tillage then lead to deposition of soil. behind the ridge, eventually resulting in either a level interval between ridges or a stable slope (Figs. 48, 67, 98). To accommodate the subsequent desposition, the ridge or wall must be periodically raised. Although a level interval results in least erosion and more uniform distribution of water, a stable slope is more adaptable to shallow soils because it permits wider spacing of the ridges and, consequently, is more suitable for mechanized crop production. Barber et al. (1980), Gill (1979) and Jacobsen (1966) presented design criteria for establishing these types of bench terraces.

Fig. 98 Partial levelling of land in Korea to reduce the potential for erosion (FAO photo)

The shape of the area between terraces is of relatively little importance where crop production is accomplished by hand labour, draught animals, or small tractors, provided the areas are large enough to accommodate the equipment and are readily accessible. In extreme cases, as on bench terraces on steep slopes, crop production is practical only with hand labour.

As size of tractor and associated equipment increases, larger and more uniform areas are needed for most effective use of all resources (land, equipment, labour, etc.) for crop production. To accommodate larger equipment, terraces should be positioned parallel to each other and at intervals compatible with equipment widths (or multiples of equipment widths). To achieve good terrace alignment, land forming, extra cut or fill along the terrace, multiple outlets, variations in grade, channel blocks and other methods can be used (Soil Conservation Service 1977). When properly designed and compatible with farmers’ equipment, terraces are more likely to be adopted and maintained for soil and water conservation. When parallel terraces are not possible, odd-shaper3 areas that cannot be easily farmed can be planted to grasses or legumes to provide feed for livestock; they can also be used for fruit and vegetable crops. Such use, however, would depend on the size of area involved, needs of the farmer, suitable markets for the products, and other factors.

5.7 DIVERSION TERRACES, WATERWAYS AND GULLY CONTROL

Two special requirements must be met when terraces are used to control erosion. First, water from upslope areas must be kept off the field and, second, water flowing from the terraces must be conveyed non-erosively from the land to suitable streams. Water from upslope areas can be kept off the field by diverting the water with diversion terraces. These are individually designed structures (channels and ridges) across a hillside to convey runoff water to a point where it will not affect the terrace system. Other uses for diversion terraces are to protect unterraced areas, divert water out of active gullies, protect farm buildings from runoff, reduce the number of waterways, and shorten the length of slope so that erosion control by strip cropping becomes more effective (SCSA 1982).

Water from graded terraces, level terraces with open ends, or level terraces with closed ends that overflow or require draining must be conveyed off the land in a non-erosive manner for overall soil conservation. On gentle slopes, water can usually be safely discharged onto adjacent grassy or wooded areas, if available; but if these are not available, then waterways are required. Waterways may be natural or specially constructed, are usually broad and shallow, and should be covered with locally-adapted, erosion-resistant grasses (Gil 1979; SCSA 1982). Grasses which form a sod, for example, Bermuda grass, are especially desirable for use in waterways. In semi-arid locations, special care must be taken to select and establish adaptable grasses which will protect the waterway from damage by erosion.

Vegetated waterways that are wide, shallow and crossable by machinery are effective for controlling erosion on slopes up to about 15 percent. On steeper slopes, vegetation will not supply the necessary protection. In such cases, vegetated waterways with drop structures of stone or other materials or waterways paved with stone are required (Gil 1979).

Drop structures in waterways are extensions of the retaining wall or ridge of terraces. Their height is less than that of the wall or ridge and is determined by the anticipated flow in the waterway. Where terraces are widely spaced, additional drops may be required. The waterway itself is protected against erosion by perennial grasses (Gil 1979).

On very steep slopes, grasses are not always practical, and the waterways are often paved with stone. Although costly, this method has the advantage that the waterway can 5e used as a path to the field. Since other access would have to be provided at additional cost, combining the waterway and path reduced overall costs and also adequately serves both purposes (Gil 1979).

Several methods are available to control erosion in gullies. Erosion in small gullies can usually be controlled by using good conservation farming practices which control the rate and amount of runoff water leaving the field and the point where the water is discharged (such as into a properly designed waterway). Where a large gully exists, a diversion terrace may be required to keep runoff from entering the gully. Once the water flow is controlled, then grass, drop structures, or permanent control structures can be used to stabilize the gully to prevent further erosion (Figs. 99, 100) If the gully is to become a part of the overall conservation system

Fig. 99 Bunch-type grasses help stabilize gullies, but are less effective than sod-type grasses (FAO photo)

Fig. 100 Check dams in gully. Silt settles behind the dams, thus filling the gully, enabling terrace construction and rehabilitation of a critically eroded area in the Upper Solo Valley, Indonesia (WFP photo, issued by FAO)

on the watershed, then gully shaping and grass establishment may be required to prepare it for use as a waterway (Constanti nesco 1976) .

A special deterrent to the use of terraces and associated structures (diversions and waterways) for water and soil conservation is the limited size of farms in many countries. Whereas land smoothing, contouring, strip cropping, etc. are adaptable to almost any sized area, terraces should cover major portions of the entire watershed to be most effective. Where farms are small, this requires that several farms be covered by one system. Unless farmers recognize the need for conservation and share the benefits from installation of the systems, they may be reluctant to participate in a programme which seemingly adversely affects their own farms.

5.8 LAND LEVELLING

Land levelling has been covered in part in Section 5.6 in relation to the CBT and bench terrace systems. By levelling the land (Figs. 101, 102), water from precipitation is more uniformly stored in soil, erosion is minimized and crop production is more uniform on the entire field.

Land levelling is also important for uniform distribution and conservation of irrigation water and water obtained from specially-treated areas and intermittent streams during periods of runoff. The areas levelled may be entire .fields, basins bounded by small dikes in a field (Figs. 101, 102), basins in adjacent to natural waterways, and specially developed catchment areas that receive water from particularly treated water harvesting areas. Special structures may be required to convey water to the field and distribute it without causing erosion. Appropriate conveyance methods, such as lined ditches or pipes, also decrease water losses due to deep percolation, seepage or use by non-crop plants (Figs. 103, 104).

5.9 WATER HARVESTING, RUNOFF FARMING AND WATER SPREADING

Water harvesting involves treating watersheds to enhance runoff and its collection to increase crop yields on limited areas (Section 5.7) or for use by livestock. Nearly all rainfall can be collected as runoff when soils are covered with asphalt emulsions, aluminium foil, butyl rubber or plastic film. However, such materials are expensive and easily damaged by livestock and wild animals. Less rainfall was captured as runoff when land was smoothed, rocks were removed and soil was sprayed with water repellents (Bertrand 1966). However, use of waxes, which are by-products of the petroleum industry, has shown promise to improve water harvesting in recent years (Fink 1982).

Water harvesting on a small scale was achieved at Mandan, North Dakota (USA), by covering ridges between 1 m spaced rows of maize with black plastic film. Runoff from the field was prevented. Maize yields averaged 4 130 and 2 410 kg/ha with covered ridges and non-treated areas, respectively (Willis 1962; Willis et al. 1963). The yield increase with covered ridges was attributed to better utilization of light rainfall, lower evaporation and higher soil temperatures in the spring.

Mickelson (1966) and Mickelson et al. (1965) constructed level basins in or adjacent to natural waterways at Akron, Colorado (USA), to intercept runoff from the waterways. Watershed to basin ratios ranged from 3:1 to 56:1. Runoff flowed into the uppermost basin until it reached a predetermined level, then flowed through or by-passed that basin to fill the next basin at a lower elevation. At sorghum planting from 1962 to 1964, available soil water contents averaged 10.2, l83.9 and 19.7 cm no contin- uously cropped (non-level), after fallow (non-level), and continuously cropped (level basin) areas, respectively. 5orghum yields on the respective

Fig. 101 Levelling land with laser-controlled scraper (photo provided by O.R. Jones, USDA-ARS)

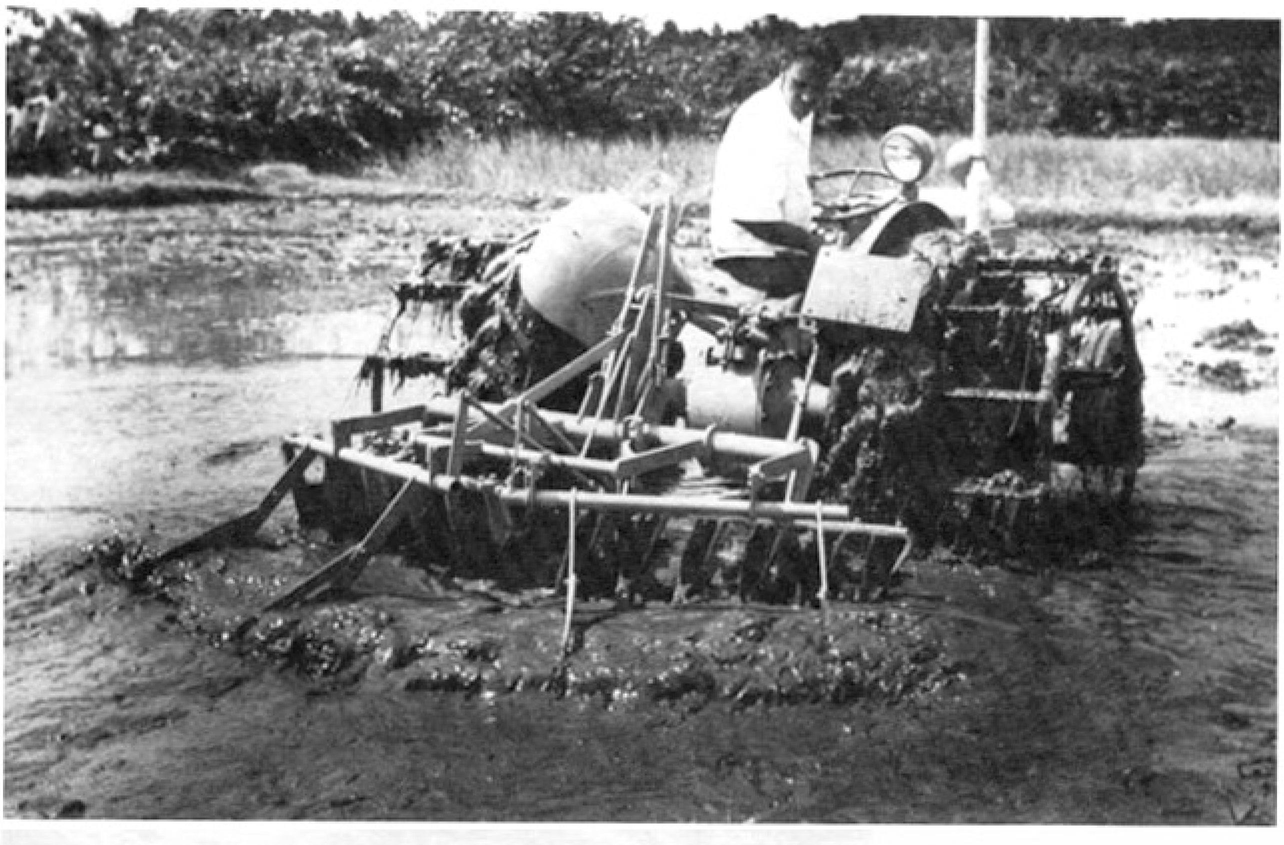


Fig. 102 Levelling land for rice production (FAO photo)

Fig. 103

Use of concrete conduits in Jordan eliminates water losses due to seepage and use by phreatophytes (FAO photo)

Fig. 104

Water rising from underground pipeline. Use of pipes reduces water losses (FAO photo)

areas averaged 350, 1 320 and 3 030 kg/ha. The major yield increase with level basins, compared with that no fallowed areas, resulted from runoff collected during the growing season, because soil water contents for these treatments were similar at planting time.

The practice of collecting runoff for crop production is an nld one, having been used for agricultural projects in the Negev Highland desert in Israel between 950 and 700 BC. Although the region receives an average of only about 100 mm of rainfall per year, concentrating runoff from surrounding watersheds permitted Evenari (1968) to grow orchard, pasture and field crops after reconstructing the collecting conduits, distribution ditches and pipes, and field areas. A system of microwatersheds that provided runoff for use by individual plants was also established. The collected water improved growth and yields of the various crops evaluated (Cohen et al. 1968; Evenari et al. 1968; Shanan et al. 1970; Tadmor et al. 1970). In the study with range plants, optimum yields were obtained with 32 m microwatersheds (Shanan et al. 1970).

A unique form of water harvesting is the capture of fog to supply water for plants or for human and animal use. The people in a small settlement on the Huri Hills in Kenya, for example, collect between 18 and 26 litres of water per day from the drippings of a large tree. In experiments in Kenya on Mount Marsabit, at an elevation of about 1 400 m, up to 6 litres of water have been collected from the air in 4 hours by using a 0.9 x 1.8 m (3 x 6 ft) vertically positioned 0.64 cm (0.25 inch) mesh screen (Seitz 1977). Such an amount of water, although relatively small, could provide sufficient water to establish trees (Seitz 1977) or produce food crops on small plots.

Water spreading is the practice of diverting runoff water from gullies or streams for spreading over relatively flat areas, mainly on range or pasture land. The water is diverted by a system of dams, dikes, or ditches (SCSA 1982). The additional water usually increases production on the flooded area at times when that on other areas may be low. The additional forage may extend the grazing season and thus increase overall livestock production. Water use efficiency with water spreading is low. However, if the water would otherwise be lost, this system may be economically advantageous if it is simple and can be constructed cheaply (Hudson N. 1981).

The foregoing systems of capturing water for crop production relied on storing the water in soil for subsequent use by plants. Another technique is to store the water in ponds during runoff periods, then use it to irrigate crops during water deficient periods. Major irrigation projects often involve water storage behind large dams. Such systems are highly complex, require intensive planning and major construction and expenses (Gil 1979); they are beyond the scope of this report. However, similar systems on a smaller scale for on-farm storage of water can lead to positive results. By storing water in ponds during rainy periods, crop production can be stabilized or improved by irrigating during a dry period within the rainy season or by extending crop production into the normal dry season (Charreau 1977; Gil 1979; Krantz et al. 1978; Sanchez 1977; Singh 1974). Some factors to consider regarding ponds include site selection, watershed size and condition, rainfall distribution and runoff, and water requirements of crops to be irrigated. The pond may also be used to store water for livestock and, if a minimum water depth of about 1 metre can be maintained, fish can be raised which could provide food for the farmer (Gil 1979).

5.10 MICROWATERSHEDS AND VERTICAL MULCHES

Microwatersheds and vertical mulches are often used in a combination system. However, each serves a distinct purpose. Microwatersheds enhance runoff from part of a field and concentrate the water on a relatively small area for crop use or storage in the soil. Vertical mulchs, by providing a residue-filled slot open to the surface at the site of water concentration, result in rapid channelling of water into the soil.

Vertical mulches where the surface was level saved 30-40 percent more water than did a furrow treatment under laboratory conditions. Wetting the entire surface during water application decreased water storage by 17 percent with vertical mulching. When a microwatershed was added, 7-10 percent more of the water was stored with a vertical mulch than without. Depth of water penetration and amount of dry surface soil adjacent to the mulch were factors that affected evaporation from vertically mulched soil (Fairbourn and Gardner 1972).

A vertical mulch resulted in saving 16 percent more water than a nonmulched microwatershed and 41 percent more water than a control treatment (no watershed or mulch) under field conditions at Akron, Colorado (USA). Check dams across the surface were an important feature of the microwatershed system. With the vertical mulch treatment, sorghum grain yields were from 37-150 percent higher than with the control treatment (Fairbourn and Gardner 1974).

As expected, a vertical mulch on Olton clay loam at Lubbock, Texas (USA), did not affect soil water contents and yields in a year (1970) without runoff. However, in 1971, runoff increased water contents at the 30-90 cm soil depth in vertically mulched plots. The water contents remained higher throughout the growing season of sorghum, which yielded 2090, 2490 and 3110 kg/ha of grain on control, vertical mulch and vertical mulch with oil (sprayed on soil between rows) plots, respectively. The differences were statistically significant (Wendt 1973a). A vertical mulch had little effect on water infiltration and crop yields on Pullman clay loam at Bushland, Texas (USA), when the land was disked after installing the mulch (Hauser and Taylor (1964). The mulch must extend to the surface to permit rapid water entry into the soil.

Trenching of Harlington clay in south Texas to 61 or 102 cm depths and backfilling the trenches with soil or vermiculite increased water infiltration rates, decreased soil bulk density in the trenches, increased rooting depth of cotton and decreased soil salinity. Cotton lint yields were significantly increased by trenching in 2 out of 3 years, with the 61 cm deep trench filled with vermiculite resulting in the highest average yield (Heilman and Gonzales 1973).

5.11 MULCHING

Crop residues, which are a type of mulch, have been mentioned repeatedly in foregoing sections with respect to their value for controlling wind and water erosion, and for conserving water. However, many other materials have been used as mulches. Ancient Romans placed stones and Chinese placed pebbles from streams on soil to conserve water (Jacks et al. 1955). Such practices may be practical where labour is abundant, but not for modern, large-scale, mechanized agriculture. However, some artificial mulches, besides the crop residues mentioned in other sections, may be practical for some high value crops. Materials used for mulching have included plastic films, paper, crude oil, gravel, bitumen, coal, etc. (Fairbourn 1973, 1974; Fairbourn and Kemper 1970; Jacks et al. 1955; Unger 1971a, 1971b, 1975b; Wendt 1973b, 1973c; Wendt and Runkles 1969). The mulches usually increased soil water contents through improved infiltration and/or decreased evaporation. Consequently, crop yields were usually also increased.

5.12 COVER CROPS AND CATCH CROPS

Cover crops are close-growing crops such as grasses, legumes or small grains (Fig. 105). These crops are grown primarily for seasonal protection against erosion and for soil improvement, and usually remain on the land for less than one year (Soil Conservation Service 1977). Major disadvantages of cover crops in dryland farming areas are the difficulties in establishing the crops because of limited water supplies and, once established, the use of water that could subsequently be used by another crop.

Fig. 105 Bromegrass, which will serve as a cover crop to protect the land against erosion, was seeded in maize after the last cultivation (USDA-Soil Conservation Service photo, issued by FAO)

A catcn crop is a crop that is grown to replace a main crop that has failed (SCSA 1982). The crop may have failed because of too little or too much rainfall at the time for planting, so crop not planted; destruction by hail, excessive rainfall, insects, diseases, etc.; or failure due to drought. Catch crops have different growing seasons or other requirements to the main crop, and are therefore established when conditions become favourable. Use of catch crops provides some food or income for the producer, permits use of water that otherwise might be lost, and may provide a growing crop or crop residues during a critical period for erosion.

5.13 LAND IMPRINTING

Land imprinting (Dixon 1981a, b, c) is the practice of using a massive steel roller faced with two patterns of angular steel teefh to form relatively stable impressions (imprints) on the soil surface (Fig. 106). The imprinter is pulled by a tractor and seed, which is normally spread ahead of the imprinter, is pressed into the soil by the imprinter.

Fig. 106 Land imprinter (photo provided by R.M. Dixon (USDA-ARS)

The imprinting system was developed to improve vegetation on overgrazed and shrub-infested arid to semi-arid rangelands while protecting land against accelerated runoff and erosion. When operated on the contour, the imprinter forms a system of interconnected watershedding and water-absorbing furrows which constitute a miniature rainfed irrigation system. The sharp angular imprinting teeth crush and cut above ground plant materials, partially imbed them in soil, and deposit the remainder as a mulch on the soil surface.

The action of raindrops and runoff move seed, topsoil and plant litter into the furrows where they are concentrated along with the water to enhance the probability of successful germination and seedling establishment. The latter is further enhanced by the surface mulch which also protects the surface against sealing, thus permitting rapid and deep penetration of water into the soil, and which minimizes soil water evaporation (Dixon 1981a, b, c).

Although designed primarily to improve rangelands (Dixon 1981a), the imprinting system also has potential for soil and water conservation on cropland, especially on land covered with residues from a previous crop and which is to be cropped to small grains in semi-arid regions.

The land imprinting system per se is simple and capable of contin uous operation on rough and even rocky land. However, the underlying principles are complex and represent edaphic, agronomic, ecologic, and hydrlogic sciences and technologies. The prime requisite for successful vegetation establishment is adequate precipitation. To enhance the probability of successful establishment, imprinting should be timed with respect to anticipated rainfall. In addition, high-quality seed of suitable species or mixtures or species should be used at rates suitable for the conditions under which the plants are to be grown (Dixon 1981a).

5.14 IRRIGATION

Irrigation is highly important for crop production in many parts of the world, and the science and technology of irrigation is thoroughly covered in numerous publications. Therefore, irrigation is treated only briefly in this report, and mainly with respect to water conservation and its effect on erosion.

Opportunities for conserving irrigation water exist from the storage reservoir to the point of use by plants. However, only on-farm possibilities are considered in this report. Losses of irrigation water on the farm may result from poor conveyance systems, land preparation, application techniques and cultural practices. The greatest losses from conveyance systems result from seepage from unlined ditches or canals (Fig. 107). Substantial losses may also occur due to water being used by phreatophytes, with relatively minor losses resulting from evaporation from the free water surface. Water losses from conveyance systems can virtually be eliminated by using lined ditches or canals (Fig. 103) or, better still, by using underground pipes for main conveyance lines (Fig. 104), then surface pipes to the point of application to land.

Fig. 107 Workers irrigating cropland in Costa Rica. Using unlined ditches increases water losses from seepage and use by phreatophytes (UN photo, issued by FAO)

Poor land preparation may cause substantial losses or inefficient use of irrigation water. Land preparation will differ depending on the irrigation system used. Where water flows across the surface for distribution (furrow, basin or flooding irrigation), land should have a uniform shape or be level so that all areas receive the same application of water. Land smoothing or levelling is usually required for uniform distribution of irrigation water (Figs. 101, 102). When water is applied through a drip or sprinkler system, land preparation is less critical. However, noticeable irregularities in the land surface still cause uneven retention of water in soil, especially with sprinklers. Where this is the case, greater uniformity can be achieved by basin listing the land to be sprinkler irrigated (Fig. 94) (Aarstad and Miller 1973; Lyle 1979). Greater uniformity than with the control treatment was also achieved with a mulch on the soil surface (Aarstad and Miller 1973).

A well-designed irrigation system is based, among other factors, on soil water infiltration rates, water retention in soil and water availability. Consequently, to maximize the use efficiency of available water resources, water must be applied according to design criteria for the particular system being used. Regardless of application method (furrow, basin, flooding, sprinkler or drip), water is mainly lost either by deep percolation or runoff, or both. Poor distribution may result in low use efficiency.

Assuming adequate design of the systems, application techniques that result in low efficiencies and water losses are given on the left, with possible consequences on the right; they include:

i.	time of application too long	excessive deep percolation high amount of runoff
ii.	time of application too short	poor water distribution low amount of water storage in soil
iii.	rate of application too high	high amount of runoff low amount of water storage in soil
iv.	rate of application too low	poor water distribution excessive deep percolation at input site low amount of water storage at other sites
v.	water applied too frequently	excessive deep percolation high amount of runoff
vi.	water applied too infrequently	excessive infiltration poor water distribution.

The foregoing examples do not include losses due to evaporation and effects on crop growth and yields which are also affected by poor water application techniques.

Poor cultural practices affect irrigation water losses in the same manner as they affect water losses from precipitation. The major difference is that rate, amount and time of water application can be controlled with irrigation and, therefore, can be adjusted to the prevailing soil conditions resulting from cultural practices. However, practices to maintain adequate infiltration rates, reduce evaporation, control weeds, etc. are essential for efficient use of irrigation water.

As with precipitation, water erosion can be a serious problem with irrigation, especially when the land is poorly prepared and when the water application techniques are poor. The same factors that cause excessive water losses from runoff often also cause soil erosion, as discussed in previous sections. Although irrigation can cause erosion, it can also be managed to control erosion, both by water (from precipitation) and by wind. Control of water erosion can be achieved by irrigating to obtain timely and uniform crop establishment, thus resulting in a protective plant canopy or density at the time of greatest potential runoff and erosion. Irrigation can also be used on critical areas, such as on earthen dams, diversion terraces, steep backslope terraces, waterways, etc. to establish vegetation, which could be difficult to establish on a timely basis without irrigation, otherwise excessive erosion could occur during periods of precipitation and runoff.

In like manner to controlling water erosion, irrigation also has potential to control wind erosion by contributing to crop establishment, which could be delayed if it depended on rainfall. Control of wind erosion is further enhanced by providing the soil with water: so that it is less or non-erodible, so that tillage can be performed to create soil roughness or erosion-resistant soil ridges, and so that crops can be produced on areas which would otherwise be non-arable and highly susceptible to wind erosion.

5.15 DRAINAGE

The emphasis in foregoing sections of this report has been on soil and water conservation. However, periods of too much water can be as detrimental to crop production as too little water. Problems with excess water and poor drainage are usually most severe in high rainfall areas. However, these problems can also occur in drier regions.

The effects of excess water and poor drainage have been mentioned in a few cases. Where excess water and poor drainage are problems, water must be conveyed from land at non-erosive velocities to protect the land resources. Surface water is normally removed from land by terraces, waterways, canals, etc. by gravity flow. However, from some low-lying areas, water must be pumped across levees or dikes for final discharge from the area. Internal drainage from soils may be achieved by disrupting impervious layers in the soil, by canals, or by various types of subsurface drains which discharge into canals with final discharge by gravity flow by pumping across levees or dikes.

Drainage of excess surface water and internal soil water has been treated extensively in numerous publications, including monographs edited by Luthin (1957) and van Schilfgaarde (1974). Such publications should be consulted for detailed information on drainage systems.

Major drainage systems often involve large areas, frequently covering either a large farm or numerous smaller farms. Drainage on a small scale is also possible on small individual farms by using some basic principles of water flow and soil management. On land with a slight uniform slope, drainage can be improved by laying off crop rows in the direction of maximum slope, thus creating a natural drainage system toward the lowest point in the field where the water can be discharged into a natural or developed waterway, if available. If neither is available, the excess water would affect only a small area rather than the entire field, or it could be discharged into a pond from which the water could be subsequently used for irrigation during a dry period (Krantz et al. 1978). For fields with non-uniform slopes, the rows should drain into low areas or waterways within the field, thus improving overall drainage. For fields with unconnected low areas, drainage can be improved by connecting them with a series of ditches which eventually permit discharge into an established waterway, to the lowest point in the field, or into a pond.

For nearly level fields with relatively slow drainage, the drainage problem on a small scale can be partially overcome by developing a system of beds and furrows. For example, Krantz et al. (1978) obtained higher yields in India when crops were planted on raised beds or ridges than when flat planted (Tables 76 and 77). The beds, which were constructed with a slight gradient, provided more rapid drainage of the seed zone. Excess water was removed from the field by the accompanying furrows. However, because of the slightly sloping construction, the runoff was sufficiently slow to avoid erosion being a problem and infiltration was adequate to conserve water for later use by plants. Planting on raised beds was also recommended by Bradfield (1969) for intensive cropping where the period between rains was relatively short. Soil in beds dried more rapidly, which provided a better chance for planting before the next rain, than in areas without beds. In monsoon rainfall areas, as in other areas, timely planting is essential to maximize production where intensive cropping practices are used (Bradfield 1969).

Table 76   EFFECT OF LAND MANAGEMENT ON CROP YEILDS ON A DEEP VERTISOL (MEANS FOR 1976-77 AND 1977-78) (from Krantz et al. 1978)

Land treatment	Yield	
	Maize	Chickpea
	kg/ha	
Flat planting	2 690	650
Narrow (75 cm) ridge planting	2 790	590
Broad (150 cm) bed planting	2 800	830

Table 77   GRAIN YIELD AS AFFECTED BY PLANTING METHOD IN TWO CROPPING SYSTEMS ON DEEP VERTISOLS IN INDIA (1967-77) (from Krantz et al. 1978)

Planting method	Cropping system			
	Intercropped		Sequentially cropped	
	Maize	Pigeonpea	Maize	Chickpea
	kg/ha			
Bed planted	3 290	760	3 210	600
Flat planted	2 910	620	2 640	360

5.16   CONTROL OF DRIFTING SAND AND SAND DUNES

Sand drifting and dune formation and shifting could be avoided, in many instances, by using good water conservation and erosion control practices. However, even where such practices are used, sand drifts and sand dunes shift due to continued movement by wind (Figs. 14, 15, 108). Where such conditions adjoin cropland, crops may be damaged or destroyed or cropland may be covered, thus decreasing yields and the amount of land available for crop production.

The main requirement for controlling sand movement is to establish vegetative barriers. Where crop residues are not available, this may require partial land levelling, fertilization, mulching and planting of adapted grasses, shrubs and trees (Fig. 109). Such practices should be carried out when rains are adequate and wind speeds are lowest (Constantinesco 1976). Other means of minimizing sand movement are to erect barriers of dead shrubs, palm branches or corrugated asbestos-cement sheets, or to apply chemical emulsions (petroleum by-products, rubber emulsions, lignin materials) (Fig. 110) (ESA 1981[?]; Moomen and Barney 1981). Sand trapping materials must be replaced or raised as dunes become higher. This is labour intensive and requires a considerable amount of materials. When the areas become stabilized, drought-resistant species are planted (Bensalem 1977).

A unique approach to dune stabilization in Australia was reported by Downes (1970). Because dunes have rough, irregular shapes, they must be reshaped before alfalfa can be grown on them. This is usually accomplished by sowing a cereal rye crop around the base of the dunes, then letting the

Fig. 108 Dune encroachmant on cropland in Texas (USA) (photo provided by D.W. Fryrear, (USDA-ARS)

Fig. 109 Use of grass to stabilize dunes in Libya (FAO photo)

Fig. 110 Farmers in Turkey seeding a crop behind a fence that will serve as a windbreak and control shifting sand (WFP photo, issued by FAO)

rye trap sand as it blows off the dunes, which improves the shape of dunes. After several seasons, rye can be planted over the entire dune, and then alfalfa can also be established which provides permanent dune stability. Alfalfa is well-adapted to such conditions because its deep root system, allows it to use deeply stored water. In addition, it can withstand drought quite well (with very little growth), then grow again after rainfall (Downes 1970).

6. TYPES AND USES OF CROP PRODUCTION EQUIPMENT

Depending on the crop production system employed, one or more types of equipment will normally be required to prepare a satisfactory seedbed, plant seeds, control weeds and volunteer crop plants, apply fertilizers, and conserve soil and water resources. The equipment of a subsistence farmer may be as simple as a hoe for seedbed preparation, a pointed stick for planting, and a cutlass or machette for weed control. In contrast, the farmer employing a modern high-technology system usually has a wide array of equipment including one or more tractors, ploughs, harrows, land planes, sprayers, fertilizer applicators, planters, cultivators, and various other types of specialized equipment.

A vast array of equipment is available for all production systems. The type used in a particular system at a given location depends on such factors as availability of credit, equipment, spare parts, fuel, lubricants, trained operators, and repairmen; initial cost and expected returns; soil conditions; crops grown; and producer preferences. Some types of equipment have been mentioned in previous sections of this report. A detailed discussion of all available equipment is beyond its scope; therefore, the emphasis is on typical hand, animal-drawn and tractor powered equipment for use in clean and conservation tillage systems.

6.1 EQUIPMENT FOR CLEAN TILLAGE SYSTEMS

In a clean tillage system, objectives are to cover all plant residues and to prevent growth of all vegetation except that of the crop being produced. These objectives are equally applicable to hand, animal-drawn and tractor powered production systems. However, the method of attaining these goals varies for the different systems.

6.1.1 Hand Powered System

The basic hand implements for primary tillage are spades, forks and hoes (Figs. 2, 3). Because of the limited power available, soil loosening or turning is relatively shallow, but may be up to 25 to 35 cm in some cases (Hopfen and Biesalski 1953). With hand implements, crop residue incorporation is difficult; therefore, if large amounts are present, they are often burned or removed for other purposes before the soil is tilled, which is not conducive to soil and water conservation, as stressed in previous sections.

Hand implements for preparing the seedbed and for controlling weeds include hoes, cutlasses, machettes, rotary harrows, rotary weeders, ridgers and cultivators (Figs. 2, 3, 4, 111). Weeds may also be pulled by hand. Herbicides are rarely used. Mineral fertilizers are not commonly used, but when used they are mostly applied by hand or with simple equipment (Fig. 112). Manure is usually spread with forks (Hopfen and Biesalski 1953).

Crops are seeded by hand broadcasting; dropping seed into holes or shallow furrows opened with hoes, spades, sticks, etc.; or with hand-pulled or pushed seeders or drills (Figs. 112, 113). As a rule, broadcasting is less desirable than other methods because it wastes seed, makes cultivation and weed control more difficult, and limits the opportunity for inter-cropping and other intensive crop production techniques (Hopfen and Biesalski 1953).

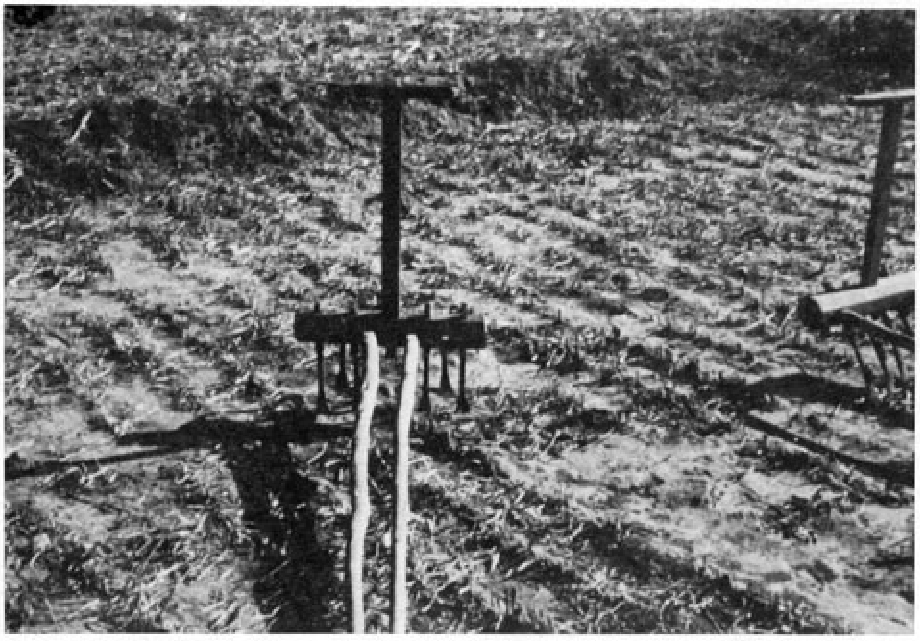


Fig. 111 Hand or animal-drawn cultivator in India (photo provided by B.A. Stewart, USDA-ARS)

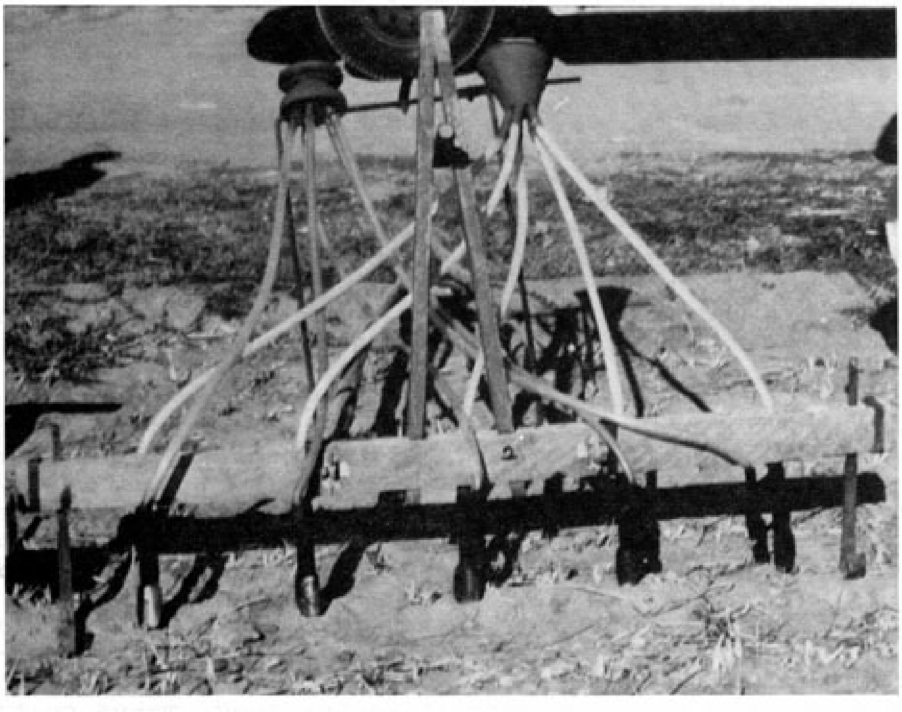


Fig. 112 Hand operated fertilizer applicator and seeder in India. The implement can also be adapted for use with animals (photo provided by B.A. Stewart, USDA-ARS)

Fig. 113 Using a hand seeder to seed grass to aid in erosion control in Tunisia (FAO photo)

6.1.2 Animal Powered System

Implements for primary tillage with animals (Figs. 5, 60, 114) have been classified as breaker, breaker-turning (or digger), and cutting-turning (Hopfen and Biesalski 1953). Breaker ploughs (Figs. 5, 114) are primarily for loosening soil, but are not effective for controlling weeds or covering vegetation and manure. Consequently, their use for clean tillage is limited to areas without crop residues (removed or burned) and where weeds are not a problem (grazed, burned, etc.).

Breaker-turning ploughs (Fig. 60) loosen soil and partially or completely invert the surface layer. Mouldboard and disk-type breaker-turning ploughs are available. Disk ploughs have the advantage of passing over rocks and roots in the soil without damage (Hopfen and Biesalski 1953). However, disks may leave the soil in a highly erodible condition due to limited surface roughness and may cause soil compaction if used when there is too much water in the profile. Neither of these ploughs, as well as the cutting-turning plough (next paragraph), should be used on dry sandy soils where the potential for wind erosion exists. Ploughing under such conditions seldom results in adequate soil roughness and aggreqate stability to provide protection against erosion. When operated in a moist sandy soil, sufficient cohesion may be achieved to provide protection against wind erosion. Further protection against wind erosion can be achieved by using a modified mouldboard plough which only partially inverts the surface layer and, thereby, retains some crop residues on the soil surface.

Cutting-turning ploughs have a share to cut the soil and a mould-board to invert the surface layer. Because they cut rather than break the

Fig. 114 Animal-drawn ploughing in front of the Colossi of Memnon near Luxor, Egypt (WFP photo, issued by FAO)

soil, these ploughs are more effective for weed control than the breaker-turning plough. A variation of the cutting-turning plough, which turns soil in one direction, is the lister (or ridger) plough, which forms alternate ridges and furrows by turning soil in two directions (Hopfen 1969). Ridges formed by lister ploughing provide protection against water erosion when ploughing is on the contour and against wind erosion when the ploughing direction is perpendicular to the prevailing wind direction.

Secondary tillage for seedbed preparation and weed control is performed with animal-drawn harrows and cultivators (Figs. 6,111). Fertilizers, when used, are usually applied by hand or simple equipment and manure is spread with a fork. Herbicides are rarely used. Seeding is by hand or with animal-drawn planters or drills (Figs. 63, 92, 112) which are often larger versions of the seeders available for hand use. Some seeders have interchangeable seed plates that permit planting of a wide variety of different crops (Hopfen 1969). Weeds are controlled after planting by animal-drawn cultivators, hand hoeing or hand pulling.

6.1.3 Tractor Powered System

The types of equipment used with small tractors are almost identical to those drawn by animals. However, the sizes and methods of attachment, depth control, etc. may be greatly different. In addition, tractors permit the use of machine-powered rotary tillers which was not possible without tractors. Such tillers are widely used with small, single-axle tractors (Fig. 62) and larger versions are available for larger tractors. Fertilizer, when used, may be applied with special equipment and manure may be spread by a tractor-drawn spreader. Weeds may be controller with herbicides in some cases, but are normally controlled by cultivation and hand hoeing.

The sizes or equipment increase as tractor sizes increase. In addition, a greater variety of equipment is normally available for use with medium to large tractors than with small tractors, and the larger tractors have enough power to combine two or more operations (Siemens and Burrows 1978).

Primary tillage is often performed with a mouldboard plough (Figs. 71, 115), which covers most residues, but results in a relatively rough surface if the soil is not too sandy and dry. Secondary tillage after mouldboard ploughing may be with tandem disks, sweep ploughs, harrows, sweep-rodweeders, or listers. Disk ploughs or harrows, listers, chisel ploughs, subsoilers, sweep ploughs and listers are also used for primary tillage in some cases (Siemens and Burrows 1978).

Fig. 115 Reversible mouldboard plough

Disk implements include disk ploughs, one-way disks, tandem disks and offset disks. Although they are highly effective for controlling weeds, they incorporate about 50 percent or more of surface residues at each operation and leave the surface relatively smooth (Fig. 16). If used three or four times, the surface is usually devoid of residues and the soil thus becomes susceptible to erosion (Fig. 116) unless the surface remains rough or can be roughened or ridged with a chisel, sweep plough or lister during a secondary tillage operation. A chisel is frequently used on disked land to loosen the soil more deeply than can be accomplished with a disk implement. For maximum soil loosening and duration of this loosening, chiselling should be done while the soil is relatively dry.

Fig. 116

Erosion by water on disk ploughed land (USDA-Soil Conservation Service photo)

Listers are used for primary tillage in some cases for row crops such as cotton, sorghum, maize, groundnuts, etc. Sometimes, the land is listed twice, with the second operation reversing the position of the furrows and ridges. Listing on the contour helps control water erosion, while listing perpendicular to the direction of prevailing wind aids control of wind erosion. Weeds on lister-ploughed land are controlled with sweep cultivators and sweep-rodweeders (Figs. 77, 81).

In situations where surface residues and weeds are limited or absent, a chisel can be used for primary tillage to loosen the soil. Chiselling requires less power than mouldboard ploughing and results in a rough cloddy surface that minimizes erosion, especially by wind (Fig. 34). Where chisels are used for primary tillage, secondary tillage is often with sweep ploughs or listers. Normally, disk implements should not be used because they greatly reduce surface roughness. However, a disking may be necessary to control a severe infestation of weeds, such as one that may develop after a prolonged rainy period.

A special problem on clean-tilled land is the disintegration and breakdown of soil aggregates and clods during rainstorms, especially on sandy soils, which results in a relatively smooth surface and can result in wind erosion within a few hours after the rainstorm. In such cases, some type of emergency tillage may be needed to control erosion and prevent sandblasting of crop seedlings by wind-driven sand.

The objective of emergency tillage is to roughen the surface so that wind speeds at the surface are reduced sufficiently to minimize erosion. Equipment suitable for emergency tillage includes chisels, rotary hoes and sandfighters (Fig. 117). Chisels are operated at shallow depths (5-10 cm) and are spaced 1-2 m apart. Thus, damage to crops, if present, is slight. Rotary hoes and sandfighters are implements that break the crust and leave clods on the surface. All such implements are usually wide and are operated at relatively high speeds and can thus cover the land rapidly when soil conditions become favourable after a rainstorm.

A range of equipment is available for applying manure, mineral fertilizers, herbicides, etc. in tractor powered systems. Manure may be applied with tractor-drawn manure wagons (Fig. 118) or with specially designed trucks, each with built-in spreaders. Various equipment is

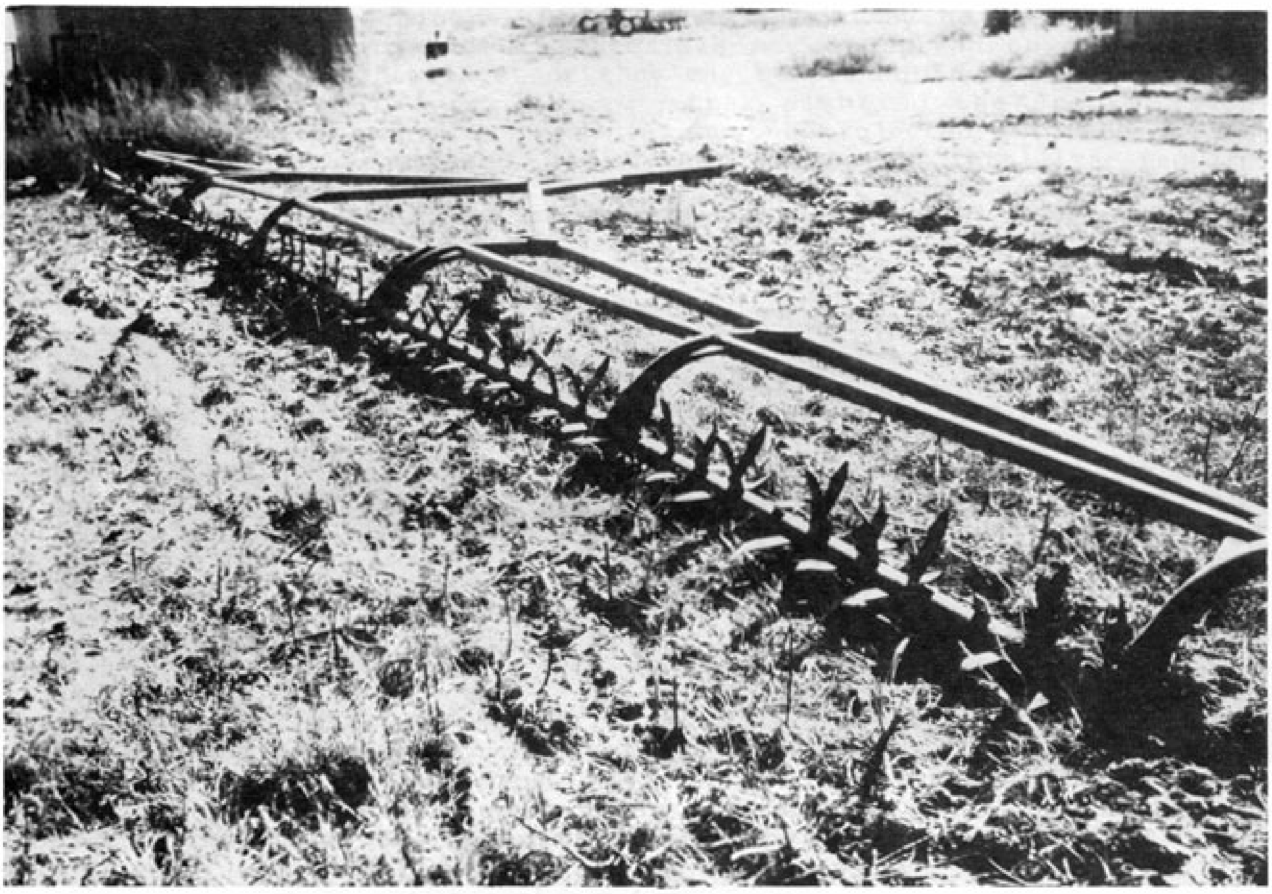


Fig. 117 Sandfighter

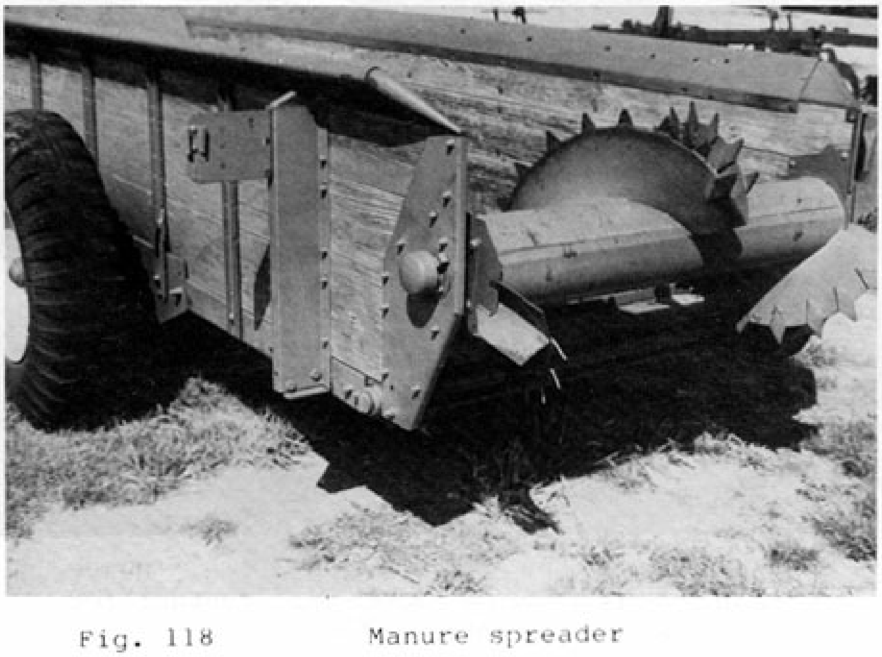


Fig. 118 Manure spreader

Fig. 119 Crop seeding with a semi-deep furrow drill. The ridges help control erosion (FAO photo)

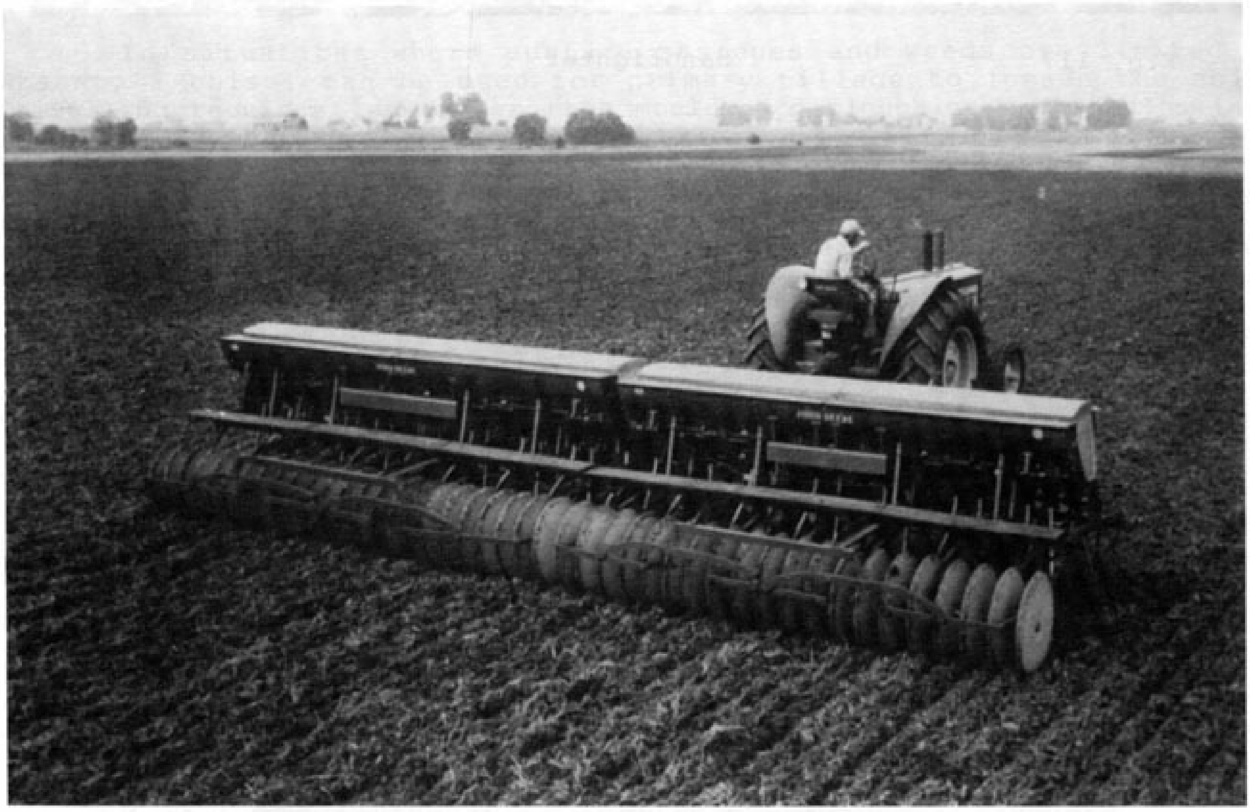


Fig. 120 Seed drill with narrow row spacing. Heavy press wheels provide seed-soil contact for good germination (FAO photo)

available for applying mineral fertilizers, which may be in a dry, liquid or gaseous form. Liquid and dry materials may be spread on the surface, then incorporater3 with tillage, or they may be placed in soil with special applicators, either before, at, or after planting the crop. Gaseous fertilizers, such as anhydrous ammonia, must be injected into the soil to avoid losses to the atmosphere. The amount and type of fertilizer required varies with soil, crop climatic conditions and production level, and recommendations for the given situation should be sought and followed to achieve maximum benefits from the fertilizer.

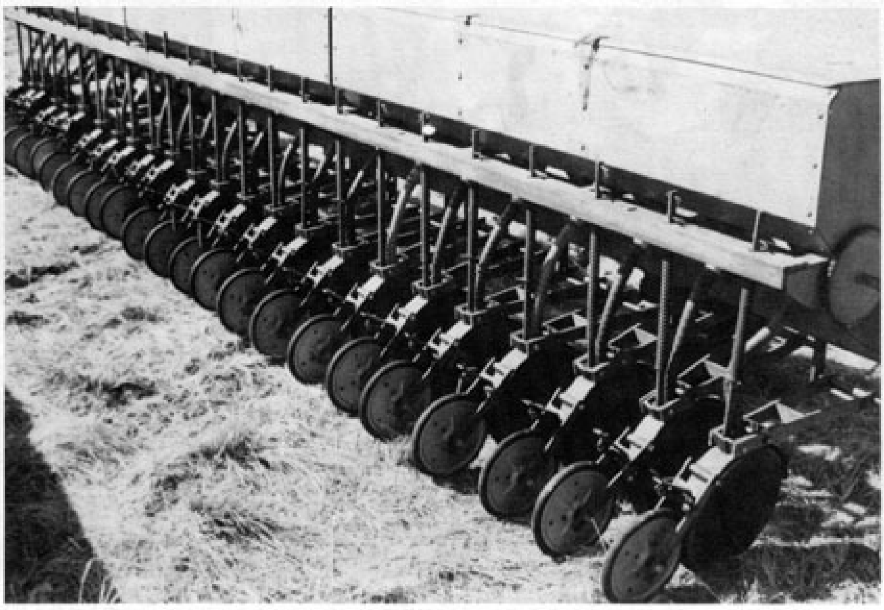
Although herbicides are normally not used for weed control before crop planting in tractor powered, clean tillage systems, they are widely used in these systems during the crop growing season. Depending on the herbicides used and weeds to be controlled, herbicides may be applied before, at or after planting the crop, and may be used to prevent weed seed germination, kill seedlings, or kill established weeds. Suitable equipment is available for herbicide applications, whether the materials are liquid or dry. Strict adherence to recommendations is essential to achieve desired and satisfactory results from the herbicides, and to avoid harmful effects on humans, animals, plants, etc. As for herbicides, suitable equipment is also available for applying insecticides, fungicides, etc. to control insects, diseases, etc. Again, strict adherence to recommendations is essential, not only to control insects, diseases, etc., but also to avoid damage to humans, livestock and the environment in general.

Crop seeding in clean tilled areas can usually be accomplished without difficulty. However, special efforts may be required to place seed in moist soil and to leave the soil in a non-erosive condition after seeding. In general, small grain crops are seeded with a drill and row crops with individual-row seeders. Seeding units are available for use with most sizes of tractors.

Drills for small grain may have shovel, hoe, shoe or disk openers (Figs. 119, 120, 121). Shovel-opener drills work well for placing seed in most soil overlain by dry soil and the ridges formed by the openers help to control wind erosion. Hoe and shoe-opener drills generally cause less ridging than shovel-opener drills.

Fig. 121

Seed drill with double-disk openers and press wheels



Disk-opener drills, with single or double disks, ridge the soil less than shovel-opener drills; therefore, they are less satisfactory for planting through dry surface soil and are also less effective for controlling wind erosion. Disk-opener drills also tend to destroy surface clods remaining from previous tillage, which further decreases their effectiveness to control wind erosion. Disk-opener drills are, however, highly effective for seeding when soil is moist at or near the surface and when the potential for erosion is slight. Press wheels to cover or firm the soil around the seed are normally used with all types of drills.

Variations of the above drills, which have openers to place the seed, are the “combine” drills, which are a combination of a cultivator and a seed drill (Rae, n.d.). 5uch drills effectively control small weeds present at seeding time and result in seeding into a relatively fine seedbed.

Row crops such as sorghum, safflower, soybean or millet are sometimes seeded with grain drills. To obtain the wider row spacing occasionally required for such crops, some seed openings are blocked to obtain the desired row spacing (FAO 1971). Row crop planting with drills can be on lister ridges or on flat-tilled land.

Lister-planters (Fig. 36) are widely used for row crops, such as sorghum and maize. The listers open furrows into moist soil and are followed by planting units that have disk, shoe or shovel openers. The lister ridges help control erosion, both by wind and water. However, this method of planting is best adapted to regions of low rainfall. Planting in furrows could cause germination and seedling emergence problems because of excessive soil water contents after planting in high-rainfall areas. Variations of lister-planters are planters that have sweeps instead of listers for tilling the soil ahead of the planting unit. Sweeps ridge the soil less than listers, but give generally good weed control in the seeding

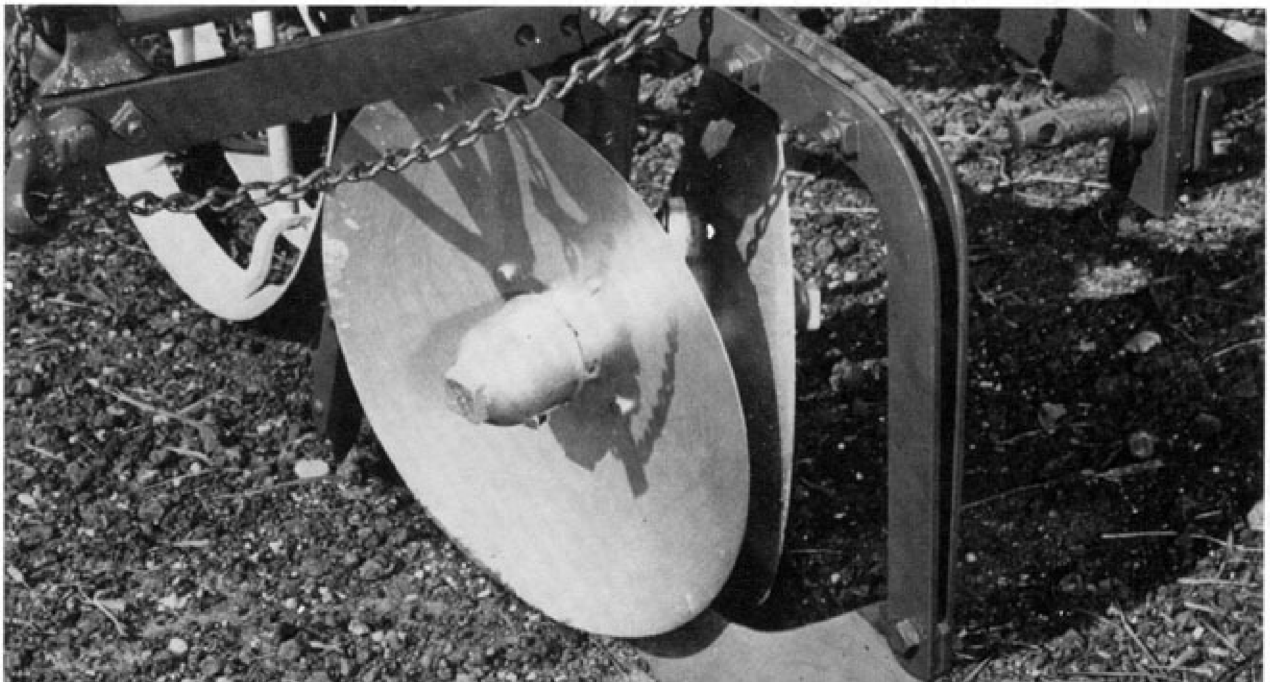


Fig. 122 Furrow opener on a maize planter (Iowa State University photo, issued by FAO)

Planters without listers or sweeps are frequently used to plant row crops on lister and on flat-ploughed land. Planters with double disk, sweep, shoe and shovel openers perform well for such planting when a clean seedbed had been prepared (Fig. 122). When certain residues, such as undecomposed plant materials are present, disk openers are usually more satisfactory than other types.

Weeds in drill-planted crops must be controlled with herbicides. In row-planted crops, they can be controlled with herbicides if suitable ones are available. Otherwise, they can be restrained by cultivation, which readily checks weeds between rows and often curbs most weeds within rows if cultivation is performed while the weeds are relatively small. In some cases, hand hoeing is required for additional weed control.

Sweep, disk, tine and rotary cultivators can be used to control weeds in crops. The type used depends on such factors as crop, weed type and size, soil conditions, equipment availability, and farmer preferences. Besides controlling weeds, cultivation of some soils creates conditions conducive to improved aeration, water infiltration, water conservation and erosion control.

6.2 EQUIPMENT FOR CONSERVATION TILLAGE SYSTEMS

In contrast to clean tillage systems for which the emphasis is on covering residues, the emphasis in conservation tillage is on reducing soil and water losses, often by maintaining residues on the surface by non-inversion tillage (SCSA 1982). Types of conservation tillage are stubble mulch tillage, minimum or reduced tillage, and no-tillage.

6.2.1 Stubble Mulch Tillage

The stubble mulch tillage system is generally not suited to hand or animal-drawn methods, but was developed for and is widely used in tractor powered systems. Stubble mulch tillage is based on subsurface tillage with sweeps or blades which undercut the surface (Fig. 39), thus severing plant roots and retaining crop residues on the surface. Sweep sizes normally range from 0.75-1.5 m wide, whereas blades may be up to 2.4 m wide. Stubble mulch machines may have several sweeps or blades so that wide strips of land can be tilled with each pass through the field. For uniform tillage on uneven land, the large machines usually have flex points where subunits of the machine are joined together (Fenster 1968). Where large amounts of residue are present, a one-way disk plough or tandem disk can be used for initial tillage to incorporate some residues with soil (Figs. 40, 72). For even greater reduction of residues, stubble busters, skewtreaders or spike-toothed harrows are used at some locations (Papendick and Miller 1977). Initial tillage is normally 10-15 cm deep with disk and subsurface’ tillage implements (Hanway 1970).

The second and subsequent tillage operations are usually shallower than the first and are performed with a sweep machine, spring-tooth cultivator, chisel plough, or rodweeder (Fig. 123). This tillage is performed as often as necessary to control weeds during the interval between crops. In certain cases, herbicides are substituted for some tillage operations (Johnson 1977; Phillips 1969; Smika and Wicks 1968; Wicks and Smika 1973; Woodruff 1972). Where troublesome weeds are present, a mulch treader (Fig. 82) may be used in conjunction with a sweep or blade implement to improve weed control (Fenster 1968; Hanway 1970). However, treaders also flatten residues, which may hasten their decomposition (Fenster 1968) and thus result in inadequate protection against erosion. The last tillage operation before seeding should be shallow, preserve surface residues, control weeds, and provide a firm seedbed in which to

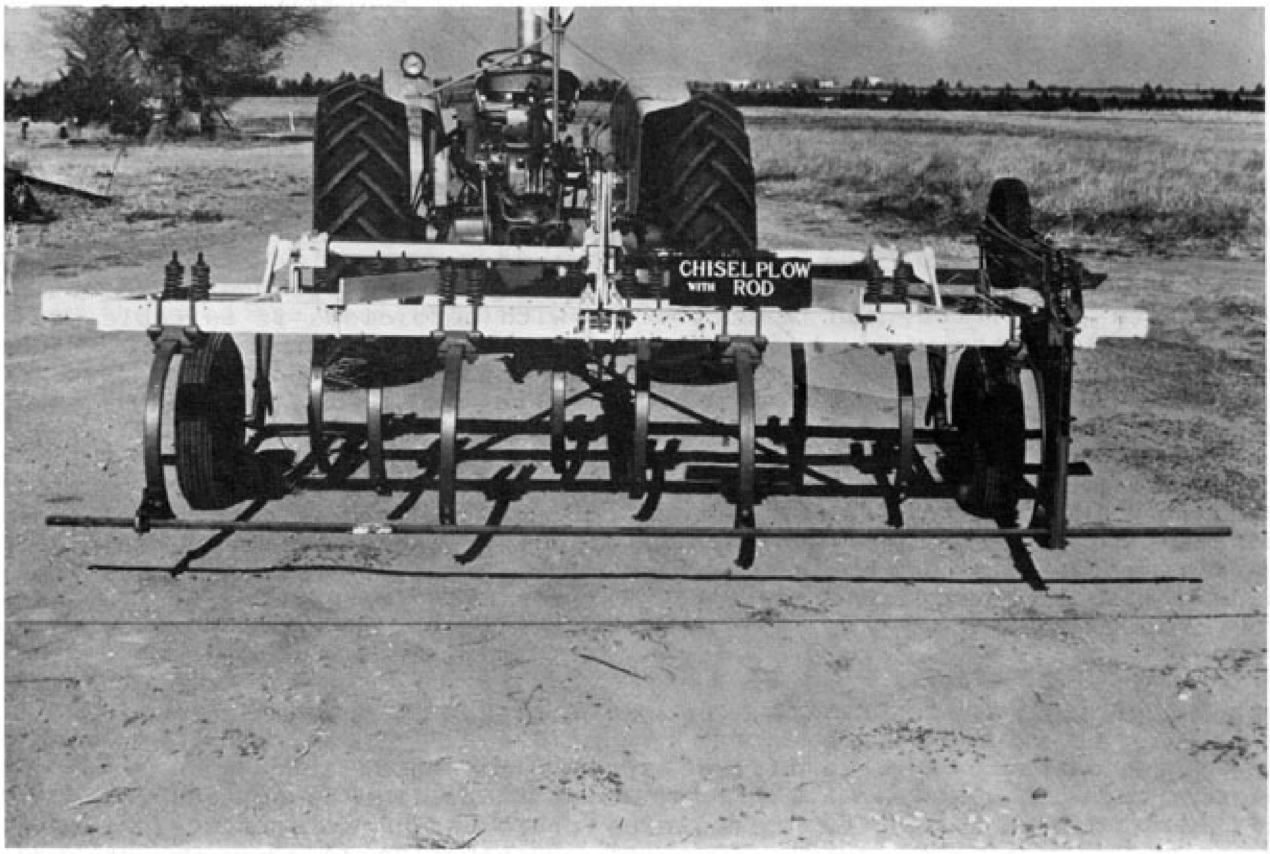


Fig. 123 Chisel plough with a rotating rodweeder (photo provided by C.R. Fenster, University of Nebraska)

Fig. 124 Deep furrow drill seeding wheat on stubble-mulched field (USDA-Soil Conservation Service photo)

plant. A rodweeder is an excellent implement for these purposes (Hanway 1970).

Fertilizers can be applied in a stubble mulch system by various means. Anhydrous ammonia can be applied with knife or chisel applicators or with a sweep or blade machine equipped with appropriate outlets. Such machines can also be used to apply solutions of N, P or K fertilizers. Dry and liquid fertilizers can be surface-applied, then incorporated with appropriate tillage. Dry P fertilizer can be applied with the seed at planting time (Hanway 1970), but N and K fertilizers should not be applied in contact with seed (Unger and Box 1972).

An important requirement for planting equipment in a stubble mulch system (Fig. 124) is that it be capable of placing seeds firmly in contact with moist soil which is in continuous contact with firm, moist soil underneath (Hanway 1970). This soil condition was the goal of tillage before planting.

A drill capable of seeding through surface residues and a layer of dry soil, and placing seed in contact with moist soil is required to establish a crop at the optimum seeding date. Small grains and millet may be seeded in drill rows spaced 18 to 36 cm apart. The wider spacings are usually used for seeding through crop residues in a stubble mulch system involving fallow. The wider rows permit a deeper furrow so that moist soil can be reached (Fig. 124). This also results in greater surface roughness which aids control of erosion and provides added protection for plants through the winter months in the case of an autumn-seeded crop (Hanway 1970).

Drills with hoe openers are widely used for seeding in stubble mulch systems. If the hoes are mounted in a staggered arrangement rather than in a straight line, the drill will have adequate clearance to permit large amounts of residues to pass without clogging it (Figs. 125, 126) (Hanway 1970). Drills with disk openers can also be used for seeding small grains (Fig. 121). However, they are less effective for seeding through a dry surface layer and provide less ridging for protection against erosion and cold winter temperatures. As for drills in clean tillage systems, press wheels are important for firming soil around the seed.

Grain drills with some seed openings blocked (if desired) can be used to seed sorghum for grain or forage in a stubble mulch system. Row

Fig. 125

Deep furrow drill with staggered arrangement of shanks and high clearance permitting operation in relatively large amounts of residue

Fig. 126

Detail of opener on deep furrow drill

spacings up to one metre may be used. Sorghum and similar crops may also be planted with unit planters behind listers, in which case, the crop is planted in moist soil at the bottom of the lister furrow. Such planting requires little seedbed preparation before planting, provides a weed-free seedbed, and provides ridges for protection against erosion. However, germination and seedling growth may be slow because of cooler temperatures in the furrow. Also, fertilizer placement may be difficult and heavy rains may move soil from the ridges into the furrow, which could bury the seed too deeply for seedling emergence (Hanway 1970).

Unit planters with disk furrow openers may be used to plant crops in rows 0.25-1.0 m apart. Such openers make a shallower furrow than listers, therefore, seedlings emerge and grow more rapidly because of warmer soil temperatures than when a lister planter is used (Hanway 1970), The disk furrow openers should also be less subject to clogging by surface residues than lister openers.

As for clean tillage systems, weed control in crops planted with drills in stubble mulch systems must be with herbicides. For row crops, herbicides or cultivation and hoeing can be used. Cultivation with sweep implements may be difficult where relatively large amounts of residue are present. In such cases, rotary hoes, rolling cultivators or disk-type cultivators may perform more satisfactorily.

6.2.2 Minimum or Reduced Tillage

Minimum or reduced tillage systems are those in which the number of field operations is reduced or in which some operations are combined. Primary or secondary tillage operations may be eliminated or combined.

Much of the crop production in Africa and Asia is through a form of minimum or reduced tillage because it saves labour, especially where facilities and equipment are limited. Examples of such systems include planting seeds in hand dug holes with relatively little other seedbed preparation except to slash weeds (Constantinesco 1976) and the dropping of seed by hand on firm moist soil behind the point of a plough, then covering the seed lightly with soil (Hanway 1970). Such practices are adaptable to hand, animal-drawn and small tractor systems. Weed control and fertilization, where practised, would be similar to that with clean tillage.

Various types of minimum or reduced tillage have been developed for use with medium to large tractors. Where primary tillage is used, it can be accomplished with a mouldboard or disk plough, chisel plough, rotary tiller, or a heavy tandem or offset disk (Hanway 1970; Papendick and Miller 1977; Rae, n.d. Siemens and Burrows 1978; Wittmuss 1968). Whatever implement is used, it should result in adequate surface roughness or residues to provide protection against erosion. Further protection against erosion can be achieved in some cases by delaying primary tillage until planting (retaining residues on the surface as long as possible) and by delaying or eliminating secondary tillage. Where secondary tillage is used, it should also be directed toward maintaining a non-erosive soil surface condition.

Except for somewhat greater dependence on herbicides to control weeds before planting, weed control in minimum and reduced tillage systems is similar to that with clean and stubble mulch systems. Also, fertilizer application and planting can be achieved by similar techniques. Planting systems for minimum or reduced tillage systems are given in Section 3.2.4.iii.b. The planting unit per se may be a drill or a unit planter, depending on crops grown and planting system used.

Weed control in established crops is with herbicides, cultivation or hoeing, depending on crops grown, availability and effectiveness of herbicides, and effectiveness of cultivation to control weeds within the row. For systems retaining relatively large amounts of surface residues, the residues may clog sweep cultivato.rs. In such systems, disk or rotary cultivators may perform more satisfactorily (Fleischer 1969).

6.2.3 No-tillage

The no-tillage system is based on the use of herbicides to control weeds and on planting the crop without any prior seedbed preparation. Consequently, a herbicide applicator, a fertilizer applicator, a seeding unit and a power source are needed for a no-tillage system. Harvesting and transport equipment are identical to other systems. However, a harvester capable of chopping or uniformly spreading crop residues helps to accomplish subsequent weed control and crop seeding in the no-tillage system (Fig. 83). Where residues are not uniformly spread, they may be removed (for example, by baling) to avoid subsequent weed control and seeding problems. Some row crops can also be planted between the accumulations of residues.

A wide range of equipment is available for applying herbicides in no-tillage systems, including various types of hand-carried and tractor-powered sprayers or applicators (Wiese in press). The knapsack sprayer is probably the most widely used hand-carried sprayer. Models of knapsack sprayers with and without pressure regulators are available (Hopfen 1969; Wiese in press; Wijewardene, n.d.). Controlled-pressure spraying is important for applying the herbicide uniformly and at the recommended rate.

To reduce the water requirement of typical knapsack sprayers (400-500 1/ha), sprayers requiring only about 40 1/ha of water have been developed. These employ either an atomizing disk or a specially. calibrated nozzle with controlled pressure to apply the herbicide solution (Bals 1975; Green et. al. 1982; Wijewardene, n.d.). Reducing the water requirement is highly important where herbicide application is by hand-carried equipment, especially where fields are at remote locations and where a supply of water is not readily available at the field. For animal-drawn systems, animals can provide means of transporting water and even the spray equipment. However, the sprayers would be the same or similar to hand-carried equipment and would normally be hand operated.

In contrast to the hand spraying system, tractors provide a means of

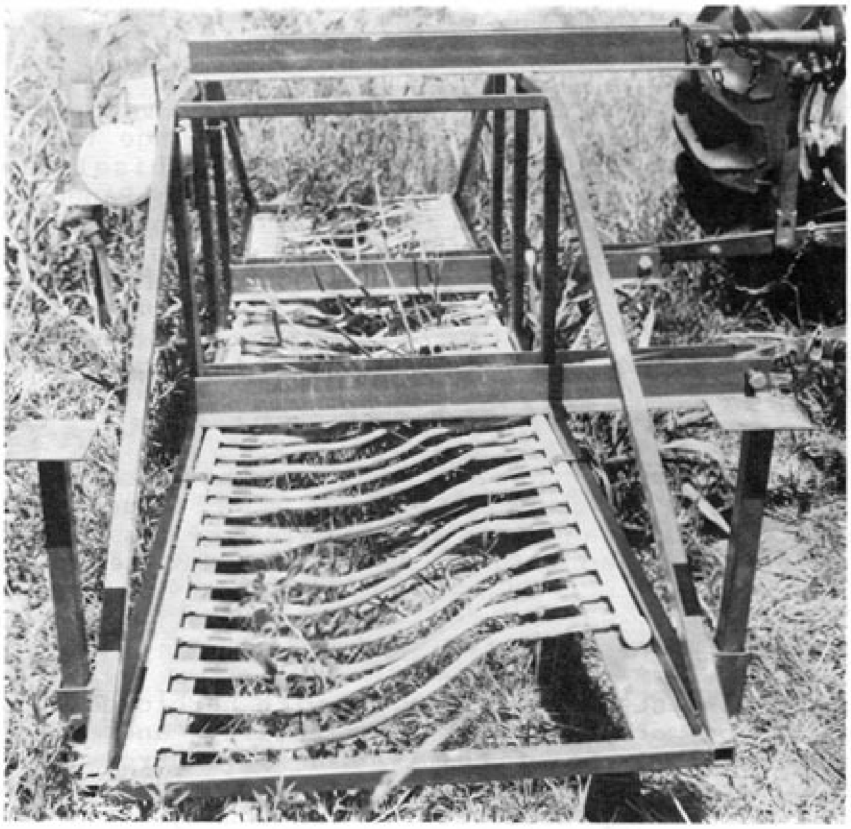


Fig. 127 Rope wick applicator for herbicides (photo provided by A.F. Wiese, Texas Agric. Exp. Stn.)

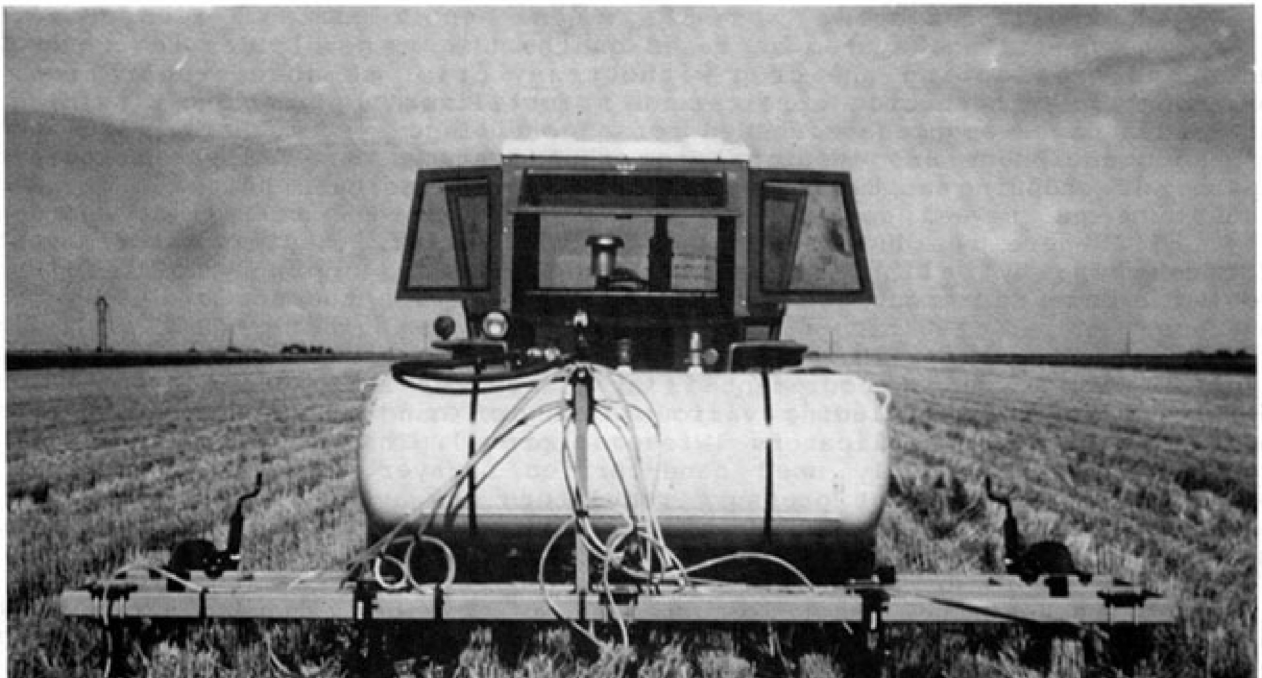


Fig. 128 Applying anhydrous ammonia with chisel equipment in non-tilled wheat residue (photo provided by R.R. Allen, USDA-ARS)

transportation for the sprayer and spray materials as well as power to operate the sprayer. Spray volume is usually less critical with tractor than with hand systems, except where the water supply is remote or limited. For such cases, atomizing sprayers could also be adapted for tractor-powered systems (Green et al. 1982). Another type of equipment that requires a low volume of herbicide solution is the rope wick applicator (Fig. 127) (Dale 1980; Wiese and Lavake 1980). For this method, a solution-saturated rope brushes against weeds, thus partially wetting them with the herbicide solution. Translocation of the herbicide within the plant kills the weed. Another sprayer that minimizes total solution requirement is the recirculating sprayer which captures and recirculates the herbicide solution not intercepted by plants (McWhorter 1970). Some herbicides are also available in a dry granular form, thus requiring no water (Wiese in press). Whatever type of herbicide or method of application is used, directions should be closely followed.

In no-tillage systems, fertilizer incorporation with soil is not possible. Hence, techniques for applying fertilizer differ somewhat from those used for tillage based systems. The technique used will depend on the type of material to be applied and the equipment available for its application. In general, materials such as urea should not be surface applied because such application results in high losses to the atmosphere. Urea, however, is the primary source of N fertilizer in many countries, and satisfactory techniques for applying it to soil of no-tillage systems still need to be developed. In contrast, good responses have been obtained from surface applications of other N fertilizers (for example, ammonium salts on acid soils) which oxidize to nitrates. Nitrates readily move with water and, therefore, move into the soil with precipitation or irrigation water. To minimize losses by leaching, split applications may be needed on some soils (Thomas et al. 1980[?]). Split applications should also reduce losses of N on sloping lands where runoff is a hazard. Good responses have also been obtained from anhydrous ammonia when it was chiselled into otherwise non-tilled soil with only minor disturbance of surface residues (Fig. 128).

Contrary to the results of many studies that indicated an advantage to band placement of such immobile nutrients as P, good results have been obtained from applying P on the surface in no-tillage systems. Thomas et al. (1980[?]) attributed this favourable response to P in no-tillage systems to the surface mulch which resulted in sufficient water in the surface soil for root growth and subsequent nutrient uptake at the soil-mulch interface. They also indicated that a surface application is essentially a band application because of minimum reaction of fertilizer with soil. Therefore, a fertilizer efficiency similar to that with band placement was achieved (Table 78). Under drier conditions, even with residues on the surface, surface applied P undoubtedly would be less available than P placed in the soil. This would also be the case where surface residues are limited. Consequently, techniques may need to be developed for improved P uptake under such conditions.

<u>Table 78</u> EFFECT OF PHOSPHORUS APPLICATION METHOD QN.MAIZE YIELD (from Thomas et al. 1980[?])

Rate of P application kg/ha	Application method: Surface	Surface + band
	maize yield - kg/ha	
0	4 650	4 770
56	7 530	5 900
112	6 280	6 150
224	6 530	6 780

The basic requirements of seeding in a no-tillage system are essentially the same as for other systems. These are to open the soil, place the seed, cover the seed, and firm the soil around the seed. However, to accomplish these in a no-tillage system usually requires some modifications to or even different equipment compared to that used in other systems.

In its simplest form, no-tillage seeding is by punching or digging a hole in soil with a suitable hand implement (stick, hoe, spade, etc.), dropping seed in the hole, covering it with soil, and firming the soil around the seed with the implement or by foot pressure. Such seeding methods are widely used by subsistence farmers, especially in shifting cultivation. Their systems usually depend on hand labour rather than herbicides for weed control.

Several types of hand implements are available for no-tillage seeding, including hand dibbers and punch planters (Hopfen and Biesalski 1953; Wijewardene, n.d.) and rolling injection planters (Wijewardene, n.d.). Where the amounts of surface residue are low, crops can also be seeded with several kinds of hand pulled or pushed seeders (Figs. 112, 113) (Hopfen and Biesalski 1953).

In animal-drawn systems, no-tillage seeders are normally larger versions of the rolling injection planters or seed drills, than those used for hand seeding. In addition, animal-drawn planters and drills are available that open a slot or furrow with a sweep, shoe or point (Figs. 63, 92, 112) (Hopfen and Biesalski 1953). These seeding units should perform satisfactorily under low residue conditions, but could become clogged with large amounts of residue because they have no provisions for cutting through the surface residues.

Much emphasis in recent years has been placed on developing suitable tractor-powered equipment for no-tillage seeding. Drills and unit planters are available (Figs. 90, 91, 121, 129). No-tillage seeders are similar to other seeders with respect to opening the seeding furrow, metering seed and placing it in the opened furrow. However, no-tillage seeders must 5e capable of cutting through surface residues and penetrating non-tilled soil, adequately covering seed with soil, and firming soil around the seed (Smith 1980(?]).

Fig. 129

Seeding wheat with deep furrow drill in residues from previous sorghum crop. No-tillage practices were used

To cut residues and to penetrate untilled soil, no-tillage seeders are usually equipped with passive rolling coulters or with power tillage blades. Coulters may be smooth, rippled or fluted (Figs. 90, 91). Smooth coulters cut residues easily, but they only cut a narrow slot and till the seed zone slightly; therefore, the seedbed may not be satisfactory. Rippled coulters have the same disadvantage. Seeding units equipped with double disk openers perform well with rippled coulters, but obtaining adequate seed coverage is difficult in many situations. Rippled coulters perform better where large amounts of surface residue are present and over a wider range of operating speeds than fluted coulters. While fluted coulters prepare a better seedbed, more equipment weight is required to obtain satisfactory soil penetration (Smith 1980[?]).

Power tillage blades cut soil in a manner similar to a circular saw cutting wood. Consequently, less equipment weight is required to obtain soil penetration than is required with rolling coulters. Powered blades prepare a satisfactory seedbed, but only one manufacturer uses them at present on no-tillage seeders (Smith 1980[?)).

A major function of any seeder is to cover seed adequately after it is placed in soil. On no-tillage seeders, knife, disk or drag coverers are used. However, seed coverage may be poor, especially where rolling coulters cut a narrow slot in firm soil or where soil penetration is poor. Seed coverage is not often a problem where power tillage blades are used (Smith 1980[?)).

Firm contact with moist soil is important for uniform and rapid seed germination and seedling establishment. Such contact is achieved with a variety of press wheels that are available for use on no-tillage seeders. Best results are achieved with press wheels that firm seed in the furrows before it is covered with loose soil (Smith 1980[?]). Firming soil over seed could cause seedling emergence problems.

No-tillage drills and row crop seeders employing the features discussed above are commercially available from numerous manufacturers. Such seeders are especially desirable for seeding where large amounts of crop residue are present and where the soil is relatively compacted because of not being tilled. Special seeders are virtually mandatory for no-tillage seeding in fields or pastures where trampling by grazing animals has caused surface soil compaction.

Where surface residue amounts are relatively low in the seed row and soil is not compacted, satisfactory crop establishment was achieved by no-tillage seeding with drills and unit planters equipped with single or double-disk openers, but without coulters ahead of the openers (Fig. 130) (Allen et al. 1975; Allen and Musick 1971; Unger and Wiese 1979; Unger et al., unpublished data, Bushland, Texas). Seeding sorghum with unit planters operating between the drill rows of a previous wheat crop was accomplished with little or no difficulty (Fig. 131) (Allen et al. 1975; Unger and Wiese 1979), even when wheat residue amounts were about 10 tons/ha. Where the amount of surface wheat residues was about 3.5 tons/ha at sorghum seeding time, seeding was satisfactory with drills and unit planters equipped with disk openers, but without coulters. Seeding direction was perpendicular to the direction of drill rows for wheat (Figs. 132, 133) (Unger et al., unpublished data, Bushland, Texas).

Weeds in established no-tillage seeded crops are usually controlled with herbicides, especially in large farming operations where tractors provide the power. However, where use of herbicides is limited and costly, and where labour is abundant, weeds can be controlled by hand hoeing, slashing or pulling. Hand labour, if available, can also be used in animal-drawn and tractor-powered systems. To minimize the labour requirement for weed control in animal-drawn and tractor-powered systems, troublesome weeds

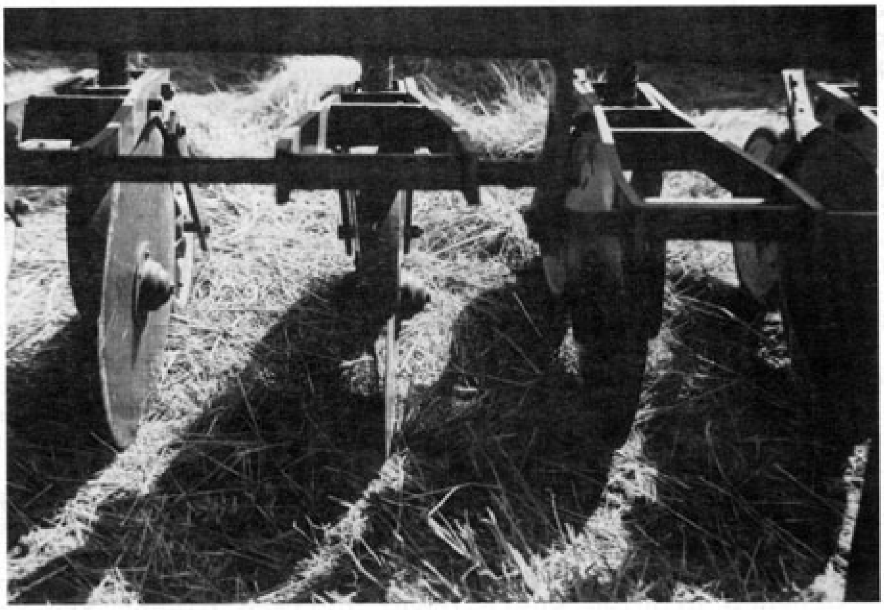


Fig. 130 Double-disk openers on a grain drill


Fig. 131 Sorghum for grain seeded by no-tillage method in wheat stubble

Fig. 132 Seeding sorghum in wheat residues with unit planters in no-tillage method

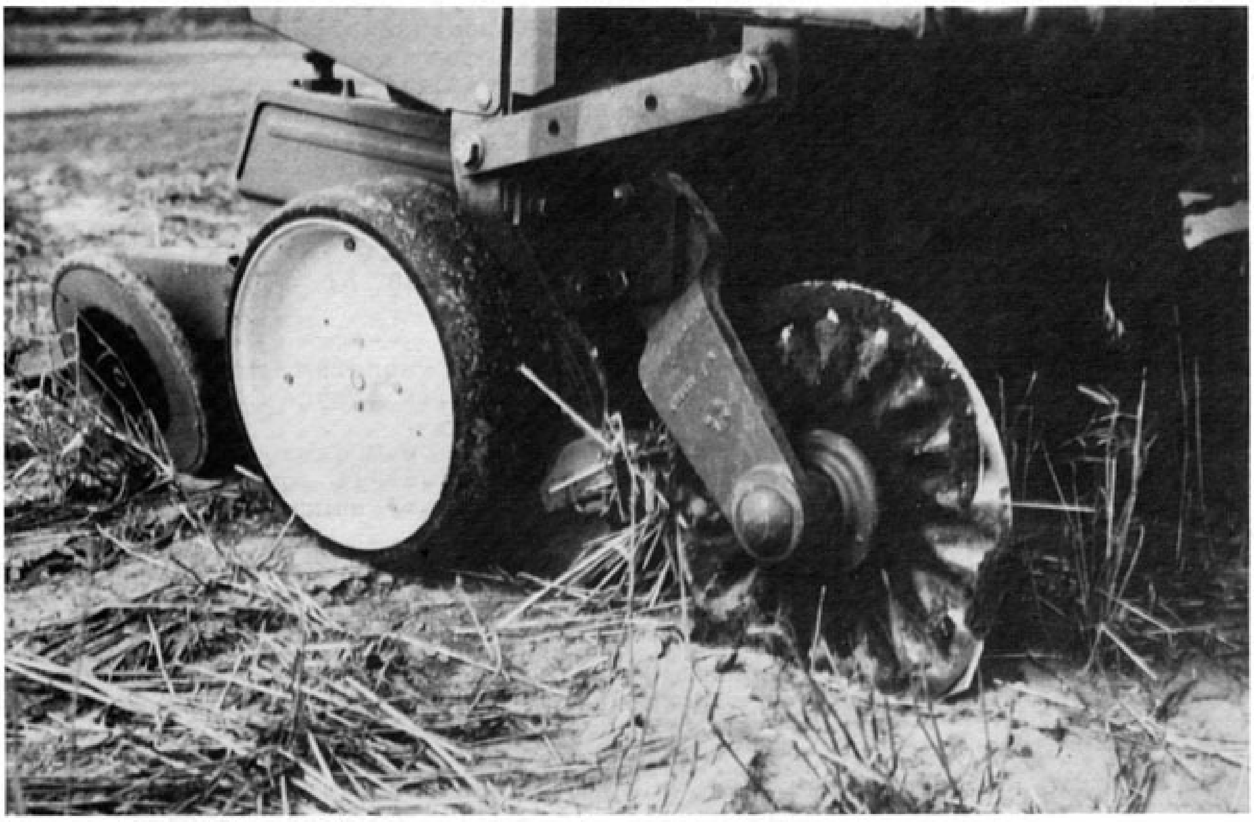


Fig. 133 Close-up view of unit planter for seeding row crops

uncontrollable with herbicides can sometimes be checked by cultivation between the seeded rows.

Where residue amounts are relatively low, sweep cultivation sometimes controls weeds satisfactorily and can be accomplished without clogging by residues. If there is much residue, coulters are usually required to cut it ahead of the sweeps. Under such conditions, disk and rolling cultivators perform more satisfactorily than sweep cultivators.

When cultivators are used, the system is no longer a true no-tillage system, but a limited tillage system. However, a cultivation may be the only means of avoiding complete loss of a crop because of weeds, and should be used if suitable equipment is available.

Other situations that are not strictly no-tillage, but which can be classified as no-tillage because less than 25 percent of the surfaces are tilled (Lessiter 1982a), are those where sweep implements undercut the soil surface to control troublesome weeds or to loosen a compacted surface layer and where chisels are used to disrupt a dense layer in the soil profile. Surface residues are only slightly reduced by such operations. However, improved weed control conserves water; loosened surface soil improves water infiltration, reduces seeding problems, and enhances plant growth; and disrupted subsurface soil layers enhance water penetration, rooting depth and proliferation, and water and nutrient use by plants.

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APPENDIX 1

GLOSSARY

ARABLE LAND: Land so located that production of cultivated crops is economical and practical.

ARID (CLIMATIC REGION): Regions that lack sufficient rainfall for crop production without irrigation. Upper annual limits of precipitation are 250 mm for cool regions and 380-510 mm for tropical regions.

FALLOW: Allowing cropland to lie idle, either tilled or untilled, during the whole or greater portion of the growing season.

FRAGIPAN: A natural subsurface horizon with high bulk density relative to the soil above, seemingly cemented when dry, but showing moderate to weak brittleness when moist.

HARDPAN: A hardened soil layer in the lower A horizon or in the B horizon caused by cementation of soil particles by organic matter or other materials such as silica, sesquioxides, or calcium carbonate. Hardness does not change appreciably with changes in water content.

HUMID (CLIMATIC REGIONS): Regions where water, when normally distributed throughout the year, should not be a limiting factor in the production of most crops. The lower limit of annual precipitation may be as low as 510 mm in cool regions and as high as 1520 mm in hot regions.

LAND DEGRADATION: The result of one or more processes which lessen the current and potential capability of soil to produce (quantitatively or qualitatively) goods or services.

MECHANIZATION: The use of mechanized equipment rather than hand labour for accomplishing crop production operations.

MULCH: A natural or artificial layer of suitable materials that aid in soil stabilization and soil water conservation, thus providing micro-climatic conditions suitable for seed germination and plant growth.

NATURAL RESOURCES: The elements of supply inherent to an area that can be used to satisfy man’s needs, including air, soil, water, native vegetation, minerals, wildlife, etc.

PLOUGH SOLE (PAN): A subsurface horizon or soil layer having a high bulk density and a lower total porosity than soil directly above or below it as a result pressure applied by normal tillage operations or other artificial means.

RATTOON: A crop production sequence in which a crop is allowed to regrow after harvest; typical of sugarcane, sorghum, etc. in a tropical climate.

RESIDUE MANAGEMENT (CROP): Use of that portion of the plant or crop left in the field after harvest for protection or improvement of the soil.

SEMI-ARID (CLIMATIC REGION): Regions where water is normally greater than under arid conditions, but water still definitely limits the growth of most crops. The upper limits of average annual precipitation are 3i30 mm for cool regions and 1140-1270 mm for tropical regions.

SHIF'TING CULTIVATION: A farming system in which land is cleared, the debris burned, and crops grown for a relatively short period. The land is then abandoned when crops are grown on newly cleared areas. The original land is cleared and cropped again after an uncontrolled fallow period of 3-20 years, usually when soil fertility has been naturally restored.

SUBHUMID (CLIMATIC REGION): Regions where water is normally less than in the humid regions, but still adequate for production of many agricultural crops without irrigation or use of dryland farming practices (mulching, fallowing, etc.). Annual precipitation ranges from 510 mm in cool regions to 1520 mm in hot regions.

TILLAGE: The operation of implements through the soil to prepare seedbeds and rootbeds, control weeds, aerate soil, and cause faster breakdown of organic matter and mineral to release plant nutrients.

Clean: Cultivation of a field so as to bury all plant residues and to prevent growth of all vegetation except that of the desired crop.

Conservation: Any tillage sequence that reduces soil or water loss relative to conventional tillage. It is often a form of non-inversion tillage that retains protective amounts of crop residues on the surface.

Conventional: The combined primary and secondary tillage operations normally performed in preparing a seedbed for a given crop in a given geographical area.

Minimum: The minimum soil manipulation necessary for crop production or meeting tillage requirements under existing soil and climatic conditions.

No-: A method of planting crops that involves no seedbed preparation other than opening the soil for the purpose of placing see at the intended depth; usually involves opening a small slit or punching a hole in soil; usually involves no cultivation during the growing season; usually involves chemical use for weed control. Also called slot planting, zero tillage, direct drilling.

Reduced: A system in which the primary tillage operation is performed in conjunction with special planting procedures to reduce or eliminate secondary tillage operations; less than conventional tillage. Similar to minimum tillage, sometimes called limited tillage.

Stubble mulch: A system of tillage that retains the stubble of crops or crop residues in place on the land, thus providing a protective surface cover before and during seedbed preparation and at least partially during the growing season of the succeeding crop.

WATER CONSERVATION: The physical control, protection, management and use of water resources in such a way as to maintain crop, grazing and forest lands; vegetal cover; wildlife; and wildlife habitat for maximum sustained benefits to people, agriculture, industry, commerce, and other segments of the national economy.

APPENDIX 2

COMMON NAMES AND SCIENTIFIC NAMES OF CROPS MENTIONED IN THE REPORT. INCLUDED ARE SOME GRASSES AND LEGUMES USED FOR SOIL CONSERVATION PURPOSES

Common name	Scientific name
Alfalfa	Medicago sativa L.
Banana	Musa sp.
Barley	Hordeum vulgare L.
Bean, castor	Ricinus sp.
Bean, dwarf	Phaseolus sp.
Beet, sugar	Beta vulgaris L.
Bermuda grass	Cynodon dactylon (L.) Pers.
Bitter leaf	Verooria sp.
Bluegrass	Poa pratensis
Cabbage	Brassica oleracea
Carrot	Daucus carota
Cassava	Manihot sp.
Citrus	Citrus sp.
Clover, red	Trifolium pratense
Coconut	Cocos nucifera L.
Cocoyam	Xanthosoma sp., Colocasia sp.
Coffee	Coffea sp.
Corn	Zea sp.
Cotton	Gossypium hirsutum L.
Cowpea	Vigna sp.
Groundnut	Arachis sp.
Maize	Zea sp.
Melon	Colocyrzthis sp.
Millet	Setaria sp., Pennisetum sp.
Oat	Avena sativa L.
Okra	Hibiscus sp.
Peanut	Arachis sp.
Peas	Pisum sp.
Peas, chick	Cicer arietinum
Peas, pigeon	Cajanus cajan Millsp.
Plantain	Musa sp.
Potato	Solanum sp.
Potato, sweet	Ipomoea batatas (L.) Lam.
Pumpkin	Cucurbita sp.

Common name	Scientific name
Radish	Raphanus sativus
Rape	Brassica napus
Rice	Oryza sativa
Rye	Secale cereale
Safflower	Carthamus tinctorius
Sorghum	Sorghum sp.
Sorghum, grain	Sorghum bicolor (L.) Moench
Soybean	Glycine max L.
Sugarbeet	Beta vulgaris L.
Sugarcane	Saccharum sp.
Sunflower	Helianthus annuus L.
Wheat	Triticum sp.
Yam	Dioscorea sp.
Others, scientific name only	Amaranthus sp.
	Capsicum sp.
	Corchorus sp.
	Dioscorea sp.
	Lagenaria sp.
	Musa sp.
	Sphenostylis sp.
	Telfairia sp.
	Voandzeia sp.

APPENDIX 3

COMMON AND CHEMICAL NAMES OF HERBICIDES MENTIONED IN THE REPORT

Common name	Chemical name
Atrazine	2-chloro-4-(ethylamino)-6-(isopropylamino)-s-triazine
Glyphosate	N-(phosphonomethyl)glycine
Gramoxone or Paraquat	l,l'-dimethyl-4,4'-bipyridinium ion
2,4-D	(2,4-dichlorophenoxy)acetic acid

APPENDIX 4

CLASSIFICATION OF SOIL SERIES MENTIONED IN THE REPORT
(UNITED STATES CLASSIFICATION SYSTEM)

Series name	Classification
Amarillo	Fine-loamy, mixed, thermic Aridic Paleustalfs
Bedford	Fine-silty, mixed, mesic Typic Fragiudults
Blount	Fine-illitic, mesic Aeric Ochraqualfs
Boone-Hixton	Mesic, uncoated Typic Quartzipsamments (Boone) - Fine loamy over sandy or sandy-skeletal, mixed, mesic Typic Hapludalfs (Hixton)
Brookston	Fine-loamy, mixed mesic Typic Argiaquolls
Catlin	Fine-silty, mixed, mesic Typic Argiudolls
Crete	Fine, montmorillonitic, mesic Pachic Argiustolls
Crosby	Fine, mixed, mesic Aeric Ochraqualfs
Flanagan	Fine, montmorillonitic, mesic Aquic Argiudolls
Foard	Fine, montmorillonitic, thermic Typic Natrustolls
Guelph	Fine-loamy, mixed, mesic Glossoboric Hapludalfs
Harlingen	Very-fine, montmorillonitic, hyperthermic Entic Chromusterts
Hoytville	Fine, illitic, mesic Mollic Ochraqualfs
Marshall	Fine-silty, mixed, mesic Typic Hapludolls
Oakville	Mixed, mesic Typic Udipsamments
Olton	Fine, mixed, thermic Aridic Paleustolls
Ottokee	Mixed, mesic Aquic Udipsamments
Plainfield	Mixed, mesic Typic Udipsamments
Pullman	Fine, mixed, thermic Torrertic Paleustolls
Rago	Fine, montmorillonitic, mesic Pachic Argiustolls
Richfield	Fine, montmorillonitic, mesic Aridic Argiustolls
Rossmoyne	Fine-silty, mixed, mesic Aquic Fragiudalfs
Runnymede	Unclassified and inactive series
Spinks	Sandy, mixed, mesic Psammentic Hapludalfs
Wooster	Fine-loamy, mixed, mesic Typic Fragiudalfs

APPENDIX 5

PEST ORGANISMS OTHER THAN WEEDS MENTIONED IN THE REPOR'T

Type	Common name	Scientific name
Insect	Armyworm (American)	Pseudaletia unipuncta
	Corn (maize) borer, southwestern	Diatraea grandiosella
	Cutworm	Various sp.
	Grasshopper	Various sp.
	Locust	Various sp.
	Root aphid, maize	Anuraphis maidiradicis Forbes
	Sod webworm, maize	Crambus mutabilis Clemens, Crambus caliginosellus Clemens, Crambus luteolellus
	Wireworm	Myelanotus cribulosus LeConte and others
Disease	Anthracnose, maize	Colletotrichum graminicola (Ces.) Wils.
	Anthracnose, soybean	Colletotrichum truncatum Glomerella glycines
	Blight, bacterial, soybean	Pseudomonas glycinea
	sclerotial, soybean	Sclerotium rolfsii
	Blight, southern, groundnut	Sclerotium rolfsii
	Blight, yellow leaf, maize	Pseudomonas alboprecipitans
	Pustule, bacterial, soybean	Xanthomonas phaseoli
	Root rot, soybean	Fusarium, Phytophthora, Rhizoctonia
	Stem rot, soybean	Sclerotinia sclerotiorum
	"Take all", small grain	Ophiobulus graminis
	Wildfire, soybean	Pseudomonas tobaci
Other	Slugs	Deroceras laeve Muller
	Rodents	Various sp.

APPENDIX 6

COMMON AND SCIENTIFIC NAMES OF WEEDS MENTIONED IN THE REPORT

Common name	Scientific name
Amaranth, Palmer	Amaranthus palmeri S. Wats.
Barnyard grass	Echinochloa crusgalli (L.) Beauv.
Bermuda grass	Cynodon dactylon (L.) Pers.
Bindweed, field	Convolvulus arvensis (L.)
Brome, downy	Bromus tectorum (L.)
Buffalo bur	Solanum rostratum Dun.
Bursage, woollyleaf	Franseria tomentosa Gray
Cheatgrass	Bromus secalinus (L.)
Chess, hairy	Bromus commutatus Schrad.
Cocklebur	Xanthium sp,
Crabgrass	Digitaria sanguinalis (L.) Scop.
Foxtail	Setaria sp,
Henbit	Lamium amplexicaule L.
Johnsongrass	Sorghum halepense (L.) Pers.
Knapweed, Russian	Centaurea repens L,
Kochia	Kochia scoparia (L.) Shrad.
Lovegrass, Pursh	Eragrostis sp,
Mustard, tansy	Descurainia pinnata (Walt.) Britt.
Nettle, horse	Solanum carolinense L.
Nightshade, silverleaf	Solanum elaeagnifolium Cav.
Nutsedge	Cyperus sp.
Panicum, fall	Panicum dichotomiflorum Michx.
Pigweed	Amaranthus sp,
Puncture vine	Tribulus terrestris L.
Quackgrass	Agropyron repens L,
Sandbur	Cenchrus sp,
Spurge, leafy	Euphorbia esula L.
Thistle, Canada	Cirsium arvense (L.) Scop.
Thistle, perennial sow	Sonchus arvensis L.
Thistle, Russian	Salsola kali L,